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JOURNAL of the AIR POLLUTION CONTROL ASSOCIATION

STACKS

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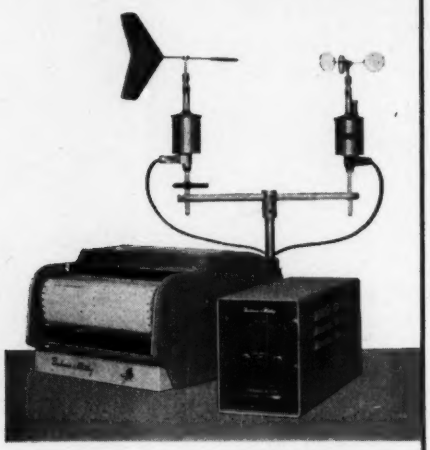
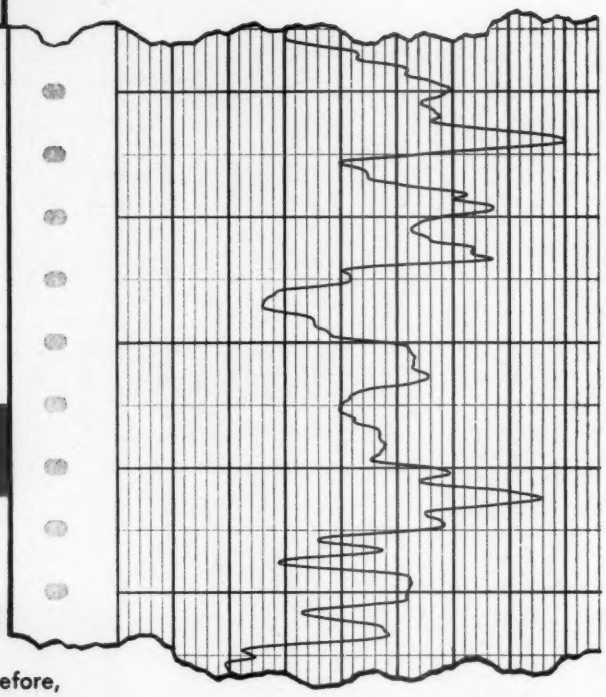
Charles W. Gruber, Conference Chairman for APCA's 53rd Annual Meeting

August 1960
Vol. 10, No. 4

WRITTEN BY THE WIND





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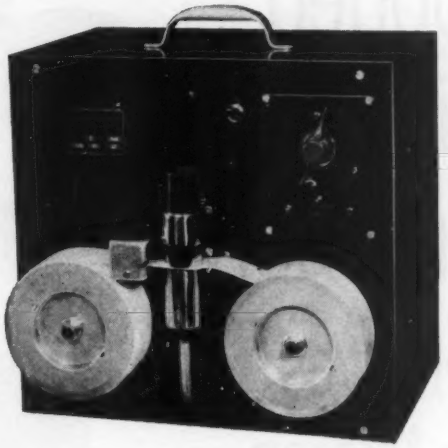

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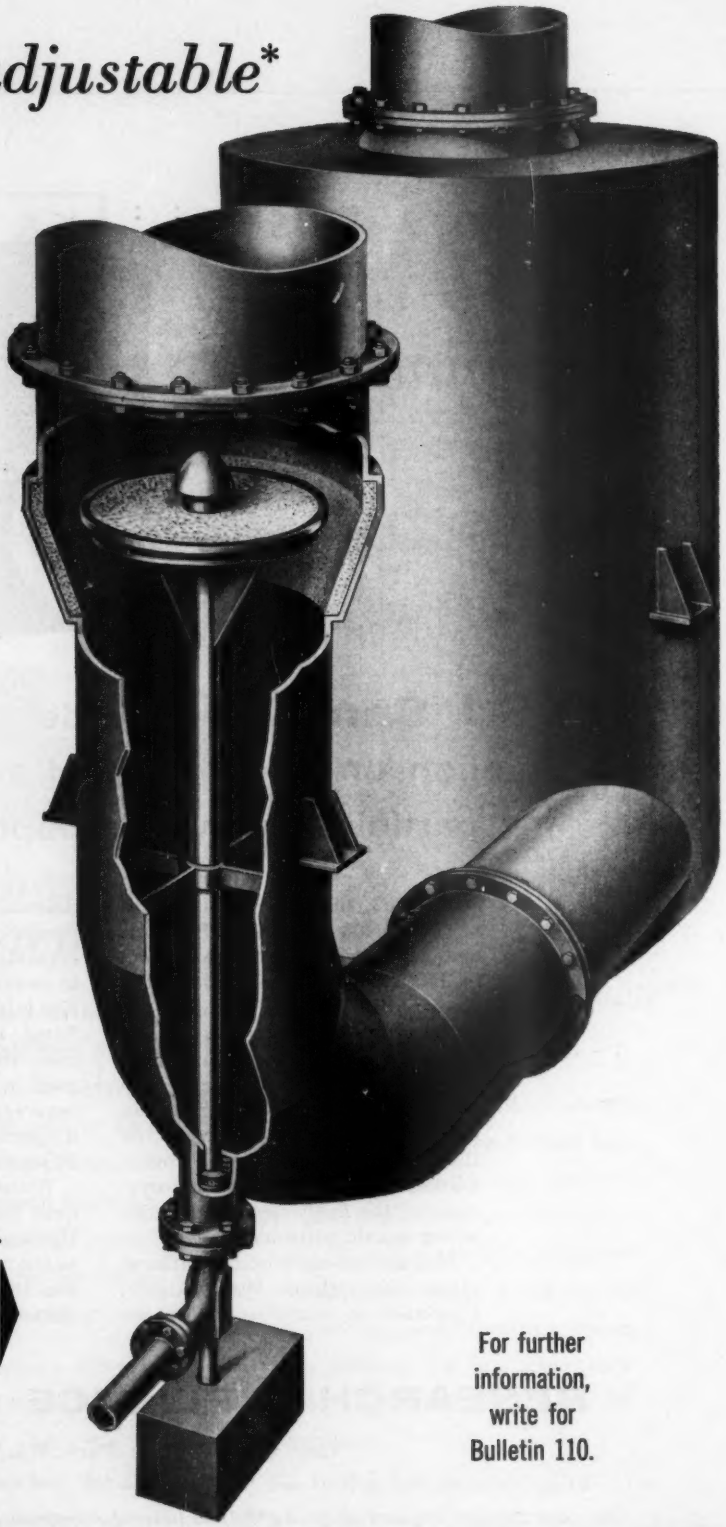

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of the

AIR POLLUTION CONTROL ASSOCIATION

HOTEL COMMODORE, NEW YORK, N. Y.

MAY 28–JUNE 1, 1961

Papers for presentation at this meeting are being solicited, and any interested authors should submit, before October 15, 1960, three copies of the title and abstract to the Chairman of the Committee on Technical Papers and Program:

George T. Minasian
Director of Community Relations
Consolidated Edison Co. of N. Y.
4 Irving Place
New York 3, N. Y.

If your paper is selected for presentation by the Committee—three copies, including one clear-cut black original suitable for photographic reproduction, of the complete manuscript must be sent to Arnold Arch, Executive Secretary of APCA, Pittsburgh, Pa., not later than February 1, 1961. This will permit preparation of preprints of all papers in time for distribution at the meeting.

Papers submitted for this meeting may not be offered for publication elsewhere than the *Journal of the Air Pollution Control Association* unless specific written release is obtained from the Association. The Association will, however, give the author not later than three months after the date of presentation of the paper either a firm commitment that the paper will be published in the *Journal* of the Association or a release for publication elsewhere.

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JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

A Bi-Monthly Journal
Devoted to
Air Purification

Editor: Arnold Arch
Associate Editor: Pat Truschel
Assistant Editor: Pat Martin

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Printed in the United States

AIR POLLUTION CONTROL
ASSOCIATION
4400 Fifth Avenue
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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

THE JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION is published February, April, June, August, October, December with editorial and executive offices at 4400 Fifth Avenue, Pittsburgh 13, Pa.

Second class mail postage paid at Pittsburgh and at additional mailing office.

Subscription price $10.00 per year.
Foreign subscription $15.00 per year.

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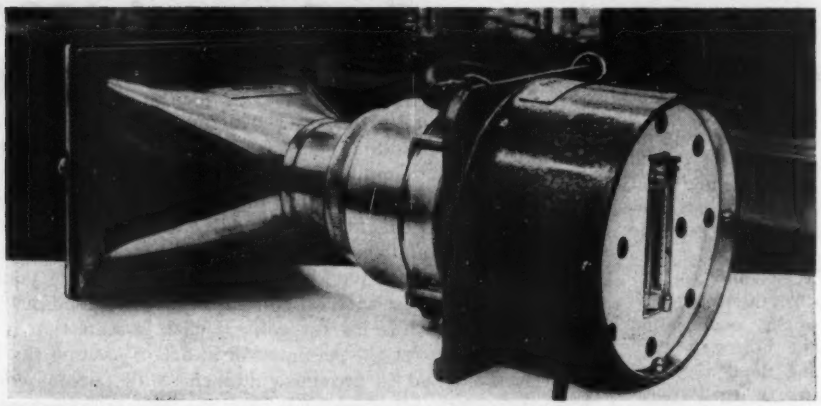

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LETTERS to the EDITOR

Editor:

Thank you for mailing the copy of your *Journal* and *Abstracts*. It will become increasingly interesting as I pursue this matter of: what has happened to the pure air which I'm sure God intended us to breathe?

Enclosed is my check and application form. In truth, "interested citizen" is my most worthy qualification for your organization. For at the pace science is maintaining these days, my Bachelor of Science (Chem-Physics-Math) 1945 is practically obsolete.

JEAN S. NICKESON

Editor:

Just a word to congratulate you on doing a fine job in the recent APCA meeting. While I could be present only two days, your persistence in making all reprints available certainly contributed a great deal to the success of the meeting. In this way, we in the air pollution field can keep abreast of progress without a six to 12 month publishing delay during which our enthusiasm is likely to ebb.

FRED W. THOMAS

Editor:

This is to advise you of my sincere appreciation for the excellent Annual Meeting of APCA in Cincinnati. I have also contacted Messrs. C. W. Gruber and A. C. Stern to express similar feelings.

Such a program can only come about by much hard work, careful planning, and co-operation. It seems to me that your efforts in this whole program were significant. I hope that the future programs can be excellent.

Best wishes for success in the coming year.

LEE SCHREIBEIS
Acting Chief
Bureau of Air Pollution Control

Dear Mr. Howison:

Let me congratulate you on the fine reports I have heard from the recent Air Pollution Control Association meeting in Cincinnati.

As chairman of the Subcommittee on Health and Safety, I believe the public must learn of the manifold problems of air pollution, and meetings such as that in Cincinnati go a long way toward making this information known.

If they are available, I would appreciate very much having copies of any papers submitted to this conference, for the attention of the Subcommittee.

KENNETH A. ROBERTS

THE PRESIDENT'S MESSAGE

The Future of APCA

It is a distinct pleasure to be afforded an opportunity to speak to you, the members of APCA, for the first time as its President, even though it is through the medium of the written word.

The outstanding success of the 53rd Annual Meeting in Cincinnati has stimulated the officers and Board of Directors in their thoughts and plans for the future of APCA. This is your Association, and to benefit you it must be alive and active. Everyone—officers, committees and members alike—must be encouraged and inspired to take part in its activities. It wants your ideas, your papers, your service on committees, and attendance at meetings.

In addition to the foregoing, I wish to state that it is important and timely for the Association to act to assume the leadership in the field and to provide guidance to all persons concerned with air pollution control. APCA is the only organization having personnel comprising all the main interests in air pollution that is able to speak without the bias attributed to industry or government. It is first of all necessary, however, that the Association be able to demonstrate the unanimity of its membership in its thinking and its desire to fulfill the proposed purposes outlined in its by-laws. I am satisfied that this is possible without compromise to the enforcement official or without unreasonable action or detriment to industry. I know one jurisdiction where this is being worked out with almost complete and unqualified success.

The main purpose of APCA is the promotion of the abatement and/or prevention of atmospheric pollution affecting health and/or causing damage to property, nuisance to the public and wasting natural resources. In this, the word promotion is an active word and in acting aggressively we should adopt the following:

1. Encourage the selection and employment of enforcement personnel or officials of ability and character acceptable to industry and to the public.

2. Provide the enforcement officials with the necessary power and freedom to act and carry out their duties, at the same time furnishing industry, etc., with a suitable medium of appeal.

3. Draft and encourage the adoption of legislation and standards adequate to control atmospheric pollution. It is possible for this legislation to be restrictive and at the same time for it to be fair and reasonable to the offender.

4. Encourage governmental research on control methods wherever and whenever industry is faced with unreasonable costs or whenever there is insufficient incentive for industry to proceed by itself.

5. By a good public relations program, inform the public that poor planning, and likewise poor zoning, by the municipality must then cause the municipality to accept prime responsibility, thus, by itself or with the help of higher governmental agencies, be prepared to assist or reimburse the industry in cases of undue expense or hardship. The acceptance and adoption of this last precept makes all other precepts or considerations reasonable.

In order to accomplish these purposes we must expand our publication program and service to the membership. The By-Law amendment on dues and structure, should it pass the membership by a two-third vote, will furnish only a small portion of the funds needed for APCA's growth.

In order to evaluate all our objectives it has tentatively been decided to form a committee of Board Members, entitled "The Future of APCA." Its mission will be to decide these weighty matters which, must be evaluated if APCA is to grow.

HARRY A. BELYEA

MONITORING *for* AIR-BORNE RADIOACTIVE MATERIALS *at Hanford Atomic Products Operation**

J. K. Soldat, Specialist, Radiological Development, Hanford Laboratories Operation, General Electric Company, Richland, Washington

The Hanford project is a complex of fuel fabrication plants, nuclear reactors, chemical separations plants, and research laboratories designed for the production of plutonium. It is operated, under government contract, by the General Electric Company through its Hanford Atomic Products Operation.

The project is located in a semi-arid region in southeastern Washington, with an annual rainfall of eight inches. Natural vegetation in the region is sparse, primarily suited for grazing, although considerable areas are being converted to irrigation. The plant site, shown in Fig. 1, comprises an area of about 500 square miles.[1]

The Columbia River flows through the area and forms the eastern boundary. The populated areas of primary interest are Richland, Pasco, and Kennewick. Other communities in the vicinity are Benton City, Mesa, and Othello. Altogether, about 80,000 people live in the region around the plant perimeter. The meteorology of the region[2, 3] is typical of a desert area with frequent strong inversions occurring at night, and breaking during the day to provide unstable and turbulent conditions. The prevailing winds are from the northwest in the plant areas with strong drainage winds causing distorted flow patterns.

Monitoring for air-borne radioactive materials is one important phase of the radiation protection program at Hanford. For purposes of discussion, the air monitoring effort can be divided into three main sections:

1. Air monitoring at work locations,
2. Monitoring of gaseous wastes discharged to the atmosphere, and
3. Atmospheric monitoring in the project environs.

The methods and equipment employed under all three headings are very similar. Some differences arise from variances in concentrations being measured.

Air Monitoring at Work Locations

Control of air-borne radioactive contamination in work locations is accomplished by careful regulation of air flow patterns. Incoming ventilation air is directed first to areas where no radioactive contamination is permitted, and then to areas of progressively higher contamination potential. A typical air flow pattern might be designed to ventilate work locations in the following order: lunchrooms, offices, locker rooms, maintenance shops, laboratories, cells containing process equipment, air clean-up facilities, ventilation fans, and finally discharge from a high stack. This type of air flow regulation ensures maximum breathing safety from a minimum of air moving equipment. In addition to this over-all flow scheme, certain individual pieces of equipment have separate exhaust and/or air clean-up arrangements.

Sampling and monitoring of working atmospheres is performed by the radiation monitoring group assigned to the plant facility involved. The results of this air monitoring are used to:

1. Ensure that air in "uncontaminated" zones is free of detectable radioactivity,
2. Determine what respiratory pro-

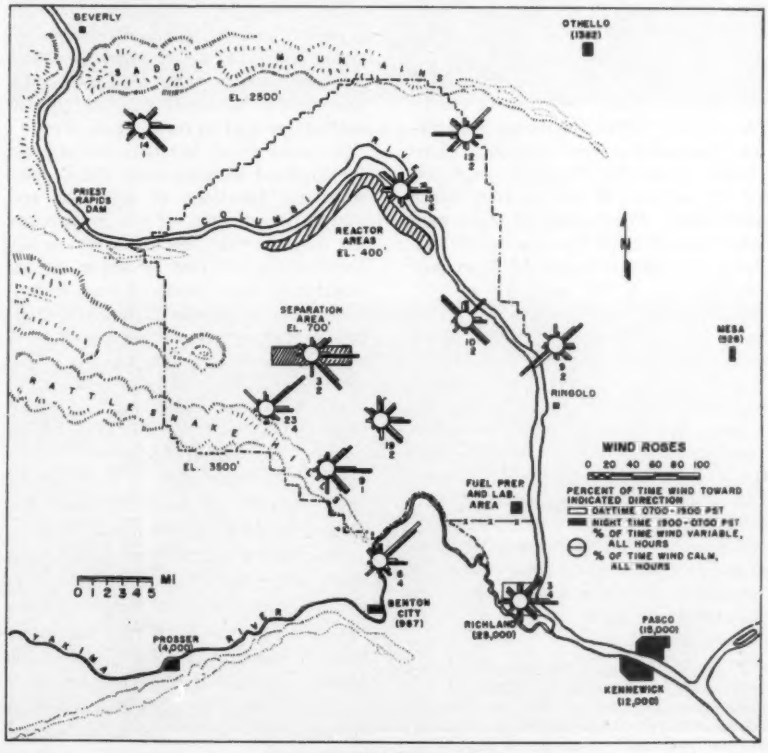

Fig. 1. Hanford Plant environs.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel June 21–26, 1959, Los Angeles, Calif.

tection is needed for entry into "contaminated" zones,

3 Establish trends in concentrations of air-borne contamination,

4 Locate sources of air-borne contamination, and

5 Record air concentrations for permanent legal records of employee exposures.

Some factors affecting the magnitude of the air monitoring program include: identity and state of radioisotopes present, layout of working space, degree of ventilation provided, and probability of generating air-borne contamination during the progress of work. In addition to these four factors, the need to collect a sufficient sample for convenient measurement of extremely low concentrations frequently must be balanced against the need to detect short-term fluctuations in concentrations.

In a discussion of methods for sampling air-borne radioactivity, presented before the APCA in November, 1954, Heslep and Bellamy mentioned that concentration by filtering was the most widely used sampling method for particulates.[4] This statement still holds true today. Recent developments in other methods have not displaced filter sampling from its number one position.

At Hanford, Hollingsworth-Vose H-70 filter paper (18 mils thick) is used with a variety of sampling equipment. Tests of the collection efficiency of this and other filter papers have been conducted at Hanford[5] and at Knolls Atomic Power Laboratory (KAPL).[6] In the tests performed at KAPL, particles whose mean size ranged from 0.2 to 1.2 microns were drawn through H-70 filter paper at face velocities of 0.5 to 250 cm/sec. The maximum penetration observed was three percent. More recently, tests at Hanford employed K_2CrO_4 particles of 0.18 microns (mass mean size). Penetration of these particles through H-70 filter paper (18 mils thick) was 0.02, 0.2, and 0.5%, at face velocities of 5, 25, and 51 cm/sec, respectively.[7] The equipment used to draw the air sample through filters varies from centrally exhausted systems of fixed piping to portable, electrically-operated air pumps. Filter holders can be attached directly to the vacuum source or to flexible hoses which permit sampling at less accessible places. Standardization of filter holder design and uniformity of filter media permit the calibration of air flow rates in terms of pressure drop across the filter paper. A simple vacuum gauge is used to measure this pressure drop.

Normally air-borne concentrations of naturally radioactive alpha particle emitters are several orders of magnitude higher than concentrations of Pu and U being sampled. To calculate the amounts of Pu and U present, it was necessary to make two or three measurements of the alpha radioactivity on the filter sample over a period of a few days. The radioactive half-life of the alpha emitters was then used as a measure of their composition. This extended period of analysis prevented immediate determination of air-borne Pu and U concentrations.

One recent solution of this difficulty at Hanford has been the development of a portable impactor air sampler. With this sampler, it is possible to collect Pu and U particulates without collecting naturally occurring radon and thoron daughter products. In the impactor, air is drawn at ~200 fps through a sharp 180° turn. The velocity is high enough to collect the relatively large, high density Pu and U particles by impaction, while the fine, light dust particles containing radon and thoron daughter products pass on through.[8]

Analysis of gross radioactivity collected by a filter or impactor sample is made with standard alpha, beta, and gamma counting equipment. Alpha counters employ either a parallel plate condenser or a zinc sulfide scintillation screen for a detector. End window G.M. tubes and beta sensitive scintillation crystals are employed for beta counting. Measurements of specific gamma emitting radioisotopes are performed on gamma energy analysis equipment. Single or 256-channel spectrometers are used to make qualitative and quantitative measurements of gamma emitters present in certain samples.

A recent trend has been toward the development of equipment which combines the functions of sampling and analysis in one unit. Such instruments are finding wide use in many fields. Applications of this principle to air monitoring have produced such instruments as continuous strip-filter monitors, counter-current flow air scrubbers, and large volume internal-flow ionization chambers. Careful selection of monitor and associated counting equipment usually permits calibration of the recorded results directly in units of air-borne concentrations. These instruments will be discussed further in the section on stack effluent monitoring.

Respiratory protection required at Hanford for entry into "contaminated" zones can be summarized in the following rule. If the air-borne concentrations of radioisotopes are less than the MPC,† no respiratory protection is required. For concentrations up to 20 times the MPC, an army assault mask is required. For concentrations over 20 times the MPC, a fresh air or "chemox" mask is needed. There are exceptions to this general rule, of course. Radioactive gases normally require the use of fresh air or chemox masks at any concentrations over the MPC.

The actual air-borne concentrations encountered at work locations at Hanford vary widely and cover the range from the lower limits of essentially contamination-free air to several times the recommended maximum permissible limit. The specifications for respiratory protection equipment, its use, and the limited amount of time spent by employees in regions of high air-borne concentrations combine to maintain personnel exposures to within a small fraction of the established maximum permissible limits.

Monitoring of Separations Plants Effluent Gases

Monitoring of radioactive wastes released to the project environs is performed by an environmental radiation monitoring group. This group is responsible for measuring, recording, and evaluating radiation exposures in the project environs and in the communities surrounding the project. As part of this responsibility, this group maintains inventories of radioactive wastes discharged to the environs, by means of direct monitoring or through compilation of monitoring results obtained by others.

Ventilation air and process effluent gases are potential contributors to atmospheric contamination both on and off the project. Ventilation air from reactor buildings normally contains negligible amounts of radioactive materials. The separations plant effluent gases discharged to the atmosphere contain small quantities of fission products. These gases are released through 200-foot high ventilation stacks, after treatment to remove some 99 percent of the radioactive materials present.[11] The rates of discharge of various radioisotopes are summarized in Table I.

Iodine-131 is emitted in the gaseous form, while the remaining isotopes are normally associated with particulate material. Local limits restrict the emission to ten curies per week of I^{131} from the separations plant stacks.

Table I—Emission Rates from Separations Plant Stacks, 1958

Isotope	Average Curie/day
I-131	1.2
RE + Y	0.02
Nb-95	0.01
Zr-95	0.004
Ru-103	0.004
Ru-106	0.002
Sr-89	0.0035
Sr-90	0.0005

† The Maximum Permissible Concentration for continuous occupational exposure recommended by the International Commission on Radiological Protection[9] and the National Committee on Radiation Protection and Measurement.[10]

A counter-current flow scrubber sampler is used to monitor and record I^{131} emission rates (Fig. 2). The scrubbing liquid, 0.2 normal NaOH, is pumped from a storage reservoir to the top of the packed scrubbing column at a constant rate of 5 cc per minute. Approximately 0.5 cfm of gas sample passes through a flow recording device and then into the bottom of the column. As the gas rises through the column, the caustic solution collects the I^{131}. The liquid then drains from the bottom of the column, through a "counting cell" and into a collection bottle. A static pressure balancing arrangement and a liquid level regulator maintain a constant liquid head in the column. At the "counting cell," a variety of counting systems can be used. If only gross radioactivity is to be monitored, then a simple system consisting of a G.M. tube, a count-rate-meter, and a recorder is sufficient. Monitoring for mixtures of radioisotopes may require the use of separate beta and gamma radiation detectors with gamma energy discrimination devices.

The spent caustic solution accumulated in the collection bottle can be taken to the radiochemical analysis laboratory for supplemental radioisotopic analyses or for calibration checks on the monitoring system.

For radioactive particulate materials, two types of filter monitors are employed. One type of filter sampler uses a large area (4 in. diameter circle) piece of H-70 filter paper, 18 mils thick, through which about 1.0 cfm of stack gas sample is continuously drawn. These samplers are operated for 24 hours and then the filter paper is replaced. The exposed filter is taken to the radiochemical analysis laboratory for measurements of gross activity and radioactive ruthenium. Spot checks for other specific radioisotopes are made on selected filters.

The second type of filter sampler is used for continuous monitoring and recording of emission rates of radioactive particulates. This type of sampler is shown in Fig. 3. In it, a strip of filter paper is drawn past a sampler head, either continuously or in a step-wise fashion. The exposed filter paper then passes by a counting device, such as a G.M. tube, or scintillation crystal connected to a count-rate-meter and recorder. Here again, more complex counting and recording systems can be employed to measure emission rates of individual radioisotopes.

One system combining a strip filter monitor and an air scrubber has been developed at Hanford by the Radiation Instrument Development Operation.[12] In this monitor (Figs. 4 and 5), a metered flow of stack gas sample passes first through a continuously moving strip filter and then through a counter-current

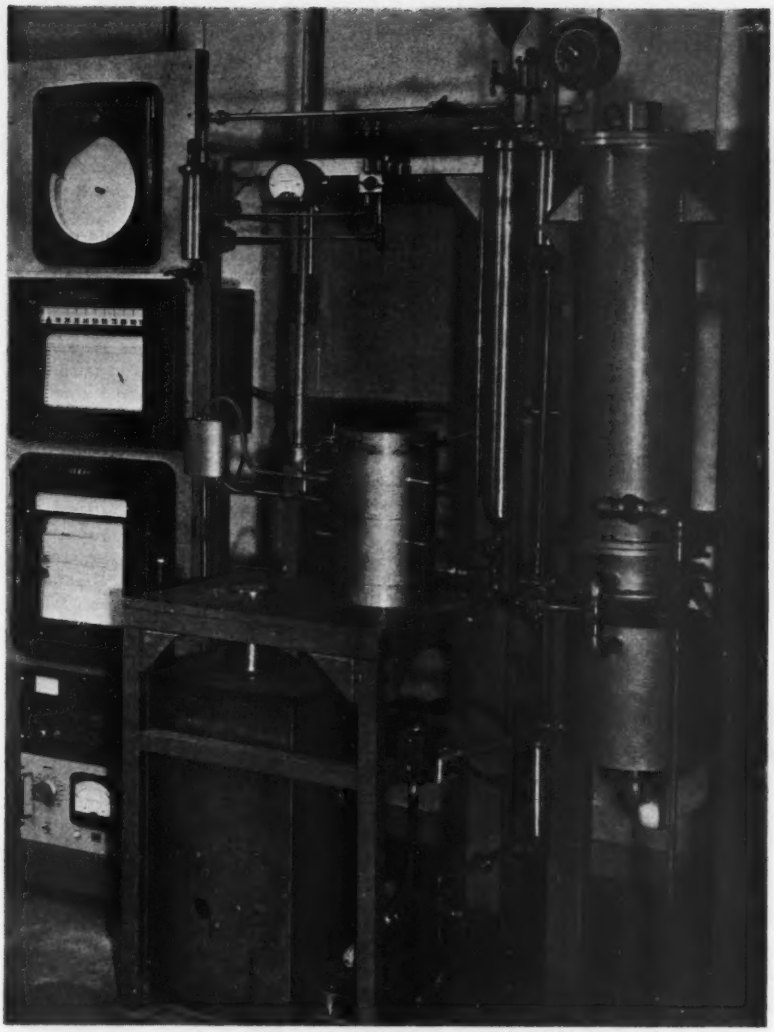

Fig. 2. Continuous I^{131} monitor.

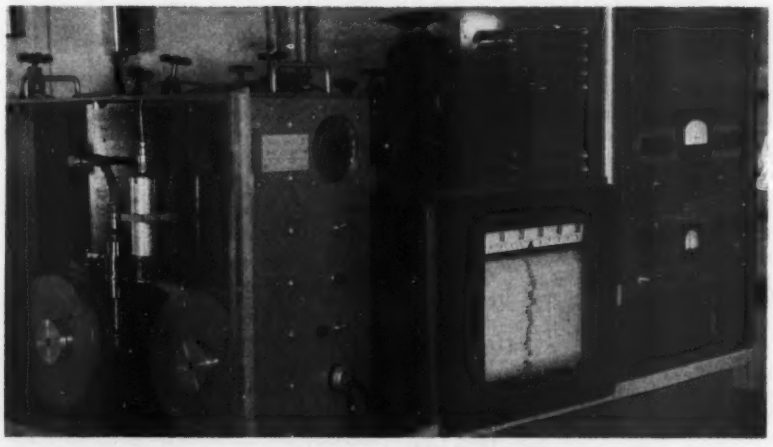

Fig. 3. Strip filter monitor.

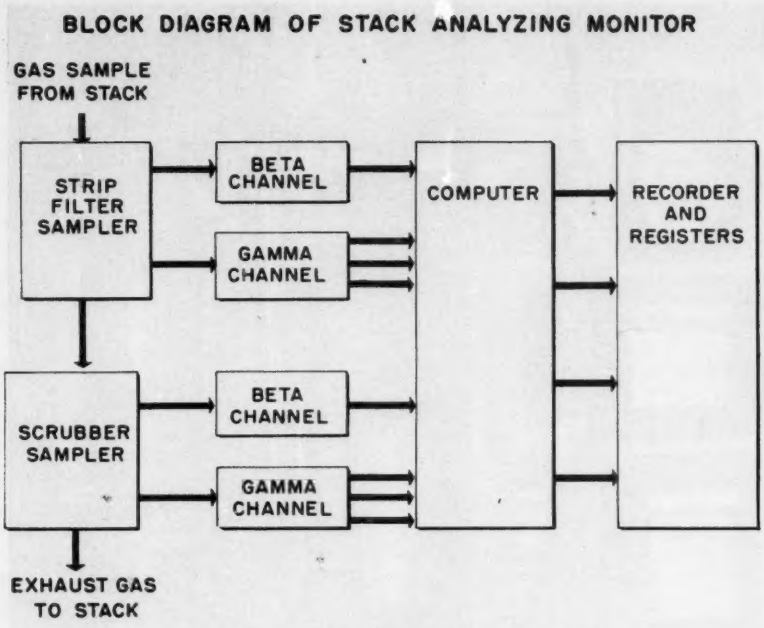

Fig. 4. Block diagram of stack analyzing monitor.

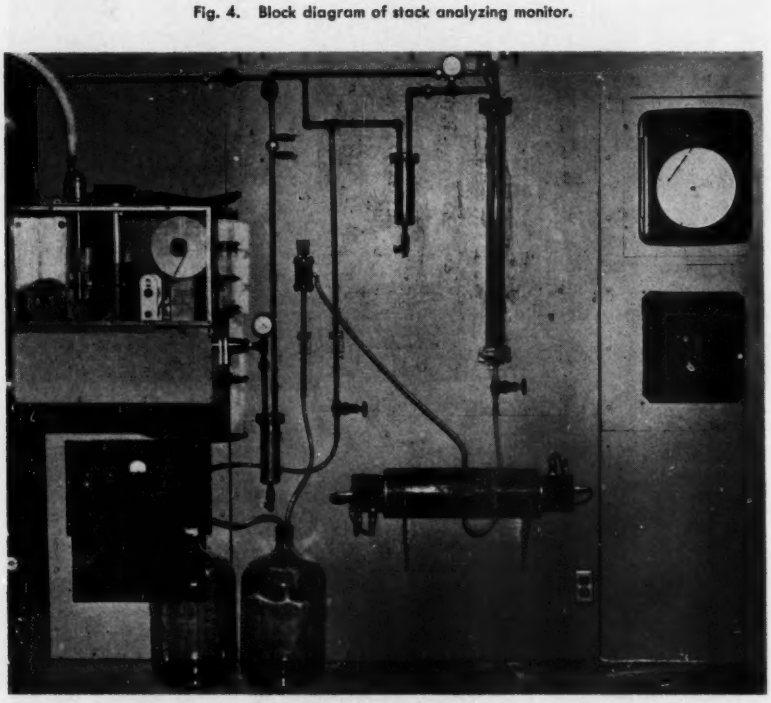

Fig. 5. Stack analyzing monitor.

flow caustic scrubbing column. Both the exposed filter paper and the spent scrubber liquid are monitored by separate beta and gamma scintillation crystals, and radiation energy discrimination devices. The counting rates from the four scintillation crystals are integrated electronically to yield recorded information on the individual emission rates of I^{131}, Ru^{103}, and Ru^{106}. Enough electronic equipment has been incorporated to provide space for measuring and recording some fourth radioisotope in the future.

This unit and the other continuous sampling and monitoring devices described are necessary aids to maintaining control limits on stack emission rates. They also allow correlation of emission rates with process operating conditions, and prediction of environmental concentrations of emitted isotopes.

Atmospheric Monitoring

One of the purposes of environmental air monitoring is to measure potential radiation exposure to the general public from the radioisotopes discharged from the separations plant stacks. In addition, two sources of radiation exposure not of Hanford origin are measured. These two are natural background radiation and radioactive fallout from nuclear test explosions.

Under present recommendations of the National Committee on Radiation Protection and Measurement (NCRP), natural background radiation can be subtracted from total radiation and the maximum permissible exposure criteria can then be applied to only the "man-made" contributions.[9, 10, 13] To perform this subtraction, however, the natural background radiation either must be evaluated separately, or must be eliminated directly from the measured radiation exposure. Separate identification of fallout and of plant contributions is a necessary aid to maintaining plant limits designed to control the release of radioactive wastes to the environs.

Air-borne concentrations of radioactive materials and radiation dosage rates are measured by equipment located in 31 atmospheric monitoring stations, and by portable ionization chambers placed at selected field locations. Twenty-seven of the monitoring stations are within project territory, while the remainder are situated in the four towns south and southeast of the project. Each station (Fig. 6) is a 6 ft x 6 ft x 8 ft high building with a louvered cupola in the roof to permit air circulation around the monitoring equipment.

Iodine-131 scrubber samplers are operated in a dozen of the monitoring stations concentrated around the separations plants. These samplers consist of a calibrated, electrically-driven vacuum pump which draws 2.0 cfm of air through one liter of 0.1 normal NaOH solution. A balancing platform and siphon arrangement permits introduction of distilled water into the scrubber at a rate equal to the rate of evaporation. This water feeder helps maintain constant liquid head, air flow rate, and scrubber efficiency.

After one week of operation, the scrubber bottle is replaced and taken to the radiochemical analysis laboratory for determination of the I^{131} content. The analytical procedure used provides for the addition of an iodine carrier and $AgNO_3$ to the scrubber solution, followed by filtration of the resulting silver iodide precipitate. The radiation from the I^{131} on the filter is measured by an end-window G.M. tube connected to a scale-of-64 scaler. Atmos-

Table II—Atmospheric Concentrations, 1958

Location	10^{-13} μc per cc			Radioactive Particles per m³
	I-131	Alpha Emitters	Beta Emitters	
On plant	5.0	<0.02	14	0.04
Plant perimeter	2.4	<0.02	12	0.04
40–100 miles	—	—	12	0.06
Over 100 miles	—	—	14	0.08

pheric concentrations of I^{131} are then calculated from these counting rates by applying factors for counter calibration, chemical recovery of the I^{131}, scrubber efficiency, and the volume of air sampled. The detection limit for I^{131} in the atmosphere using the above methods is 10^{-14} μc per cc of air.

Air-borne radioactive particulates are also sampled at selected monitoring stations. These samples are collected by drawing 2.0 cfm of air through small filters, $1^{11}/_{16}$ inches in diameter, for a period of one week. The collected radioactive materials are measured in the laboratory for gross beta activity by counting with an end-window G.M. tube—scaler arrangement. The filters are also counted for alpha particle emitters using alpha sensitive zinc sulfide scintillation equipment.

A delay period of two to three days between filter changing and alpha counting is used to permit the relatively short half-life, naturally radioactive, alpha particle emitters to decay to insignificance. The detection limits for these filter sampling and counting techniques are: 10^{-14} μc of gross beta emitters per cc of air, and 10^{-15} μc of gross alpha emitters per cc of air. The filters may also be spot-checked for specific radioisotopes by conventional radiochemical means or by use of a 256-channel gamma-ray spectrometer.

Measurements for concentrations of radioactive particulates in the atmosphere are made with two-inch by four-inch H-70 filter paper. Twenty-four of these filter samplers are operated within the project, four are operated in nearby towns, and nine others are located in remote locations scattered throughout the Pacific Northwest. The filters are changed on either a daily or a weekly schedule and then are autoradiographed using Eastman Kodak, Type-K, x-ray film. The filters are placed next to the film for one week, the filter is removed, and the film is developed. The developed film is viewed on a standard x-ray viewer and each darkened spot counted as one radioactive particle. Air-borne concentrations of radioactive particles are calculated by dividing the number of darked spots obtained per filter by the total volume of air sampled. The detection limit is one particle per filter, of 20 disintegrations per minute or higher activity. For weekly filter operation, this amounts to a detection limit of 2×10^{-3} particles per cubic meter of air (2×10^{-9} particles per cc).

Table II is a summary of the results obtained from operation of these filter and scrubber samplers during 1958.

The perimeter locations are primarily in the Richland-Pasco-Kennewick area, while those over 100 miles from the plant are in Washington, Southern Oregon, Southern Idaho, and Western Montana. The influence of debris from nuclear detonations is evident in these data. Examination of the results from individual monitoring stations indicates that locations upwind and cross-wind from the project have atmospheric concentrations of radioactive particulates equal to or greater than those locations immediately downwind of the project.

External radiation dosage rates in the project environs result from radioactive materials suspended in the atmosphere or deposited on the ground. Measurement of the low dosage rates encountered is accomplished through the use of small portable ionization chambers and a novel chamber reader developed at Hanford.[14]

Measurements made with these chambers vary with atmospheric concentrations of naturally radioactive radon, thoron, and their decay products, and with the amount of freshly deposited radioactive fallout from nuclear detonations. In the absence of fresh fallout, the results average about 0.3 to 0.4 milliroentgen (mr) of gamma radiation per day. This figure includes about 0.2–0.3 mr per day of natural background radiation, so that the Hanford contribution is on the order of 0.1 mr per day or less.

The isotopic composition of the deposited radioactive materials is determined by collecting and analyzing vegetation samples, principally grass and sagebrush, around the project and in Eastern Washington and Northern Oregon. Locally, garden produce and milk are also purchased for analysis. A large part of the environmental air monitoring program involves the study of I^{131} because of its high volatility during dissolving of the irradiated uranium, and because of its strong tendency to deposit on vegetation and other surfaces.

The amount of radioactive contamination deposited on the vegetation is measured with a 256-channel gamma-ray spectrometer. Specific isotopic concentrations are calculated from counting rates obtained at their characteristic gamma energies, after applying corrections for compton scattering and natural background radiation.[15] Strontium^{89} and Sr^{90} concentrations are determined by radiochemical separation and beta particle counting. The majority of radioisotopic measurements made on milk and produce samples are below their respective detection limits of about 10^{-7} μc per gram. Higher isotopic measurements are obtained for the grass samples because of the higher surface to weight ratio of grasses.

Fig. 6. Atmospheric monitoring station.

Figure 7 illustrates the annual average deposition pattern of I^{131} on grasses and sagebrush, based on an emission rate of one curie per day.[15] This pattern shows the influence of the prevailing winds and the frequent inversions which tend to carry the plume to long distances before it reaches the ground.

Deposition of I^{131} and particulates from the atmosphere can be followed by performing radiological surveys of the ground. These surveys are made with portable transistorized equipment employing a gamma sensitive scintillation crystal, five inches in diameter by five inches thick. The equipment can be carried by car, boat, or airplane. In the event that unusual ground contamination is detected, more detailed surveys can be made with hand portable instruments and by collecting supplemental vegetation samples.

Summary

The air monitoring program at Hanford employs a variety of equipment and techniques for measurement of airborne and deposited radioactive mate-

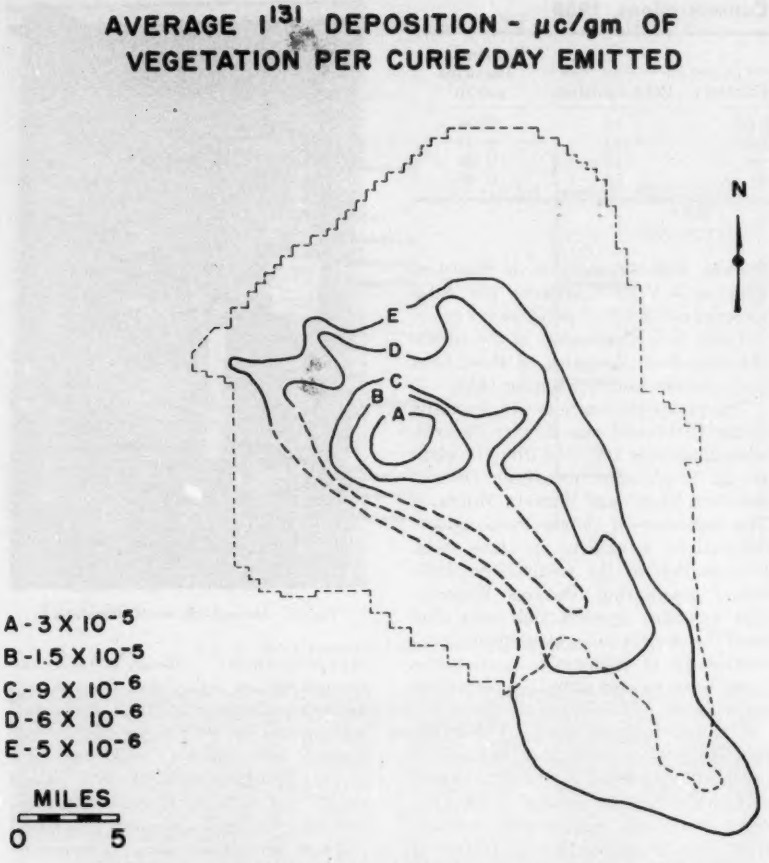

Fig. 7. Average I^{131} deposition—μc/gm of vegetation per curie/day emitted.

rials. Some of the instruments used were developed at Hanford for specific applications. The measurements made are complicated by the presence of naturally occurring radioactive materials and of radioactive fission products from nuclear detonations. Present methods are adequate to ensure that exposures of humans and grazing animals to airborne or deposited radioisotopes are well below applicable limits; however, refinements in air monitoring techniques are constantly being made.

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AIR PURIFYING BECOMES COSTLY

The nine phosphate companies operating in the Polk-East Hillsborough County area, Florida, have invested more than $11,000,000 to date in research, development and installation of waste control systems to purify air and water released from their plants, a phosphate company research engineer told a statewide meeting of industrial waste experts recently.

Dr. Randolph C. Specht, the American Agricultural Chemical Company, Pierce, reported the figure in a paper presented before the industrial wastes technical session of the Florida Sewage and Industrial Wastes Association and the Florida section of the American Water Works Association, in joint session. His subject was "Disposal of Wastes from the Phosphate Industry."

Also on the program were Dr. E. R. Hendrickson, Gainesville, chairman of the Florida Air Pollution Control Commission and an APCA member; B. Clarke Nichols, Tallahassee, assistant state attorney general and former legal counsel for the air pollution control commission, and Dr. Robert O. Vernon, Tallahassee, director of the Geological Survey.

The rapid progress being made in science and industry, Dr. Specht said, "presents a challenge to manufacturing agencies."

"As population increased and towns grew into cities, waste disposal, industrial and municipal, became more of a problem. Because of a desire by industry and its neighbors to live together, these problems of pollution have been studied and progress has been made."

The total investment in the waste control program includes $6,737,221 to purify air, the research expert said, and $4,605,202 to remove impurities from water.

During washing, sizing and other phosphate plant processes, Dr. Specht said, clear water is introduced and waste water removed at several points. The waste water is routed to large separators or settling areas where the clay and sand settle, leaving clear water which is recycled for use in the plant processes.

Discharge ELECTRODES *and Electrostatic* PRECIPITATORS*

J. S. LAGARIAS, Mgr. Metal Products Section, Koppers Company, Inc., Research Dept., Pittsburgh, Pa.

The discharge electrode is in many respects the heart of the electrostatic precipitator and a review of its functions is useful in illustrating how and why discharge electrodes are selected. Discussing precipitators through the discharge electrode functions is a little like describing a gas combustion engine by examining the operation of a spark plug in detail. In each instance a spark initiates the action. In a precipitator, however, the spark is used completely and is a primary source of energy, whereas the engine uses the spark as an initiator of a second and more powerful reaction.

Gas Cleaning Aspects

There are two broad categories of gas cleaning, the removal of solid or liquid particles suspended in a gas and the elimination of gaseous contaminants. The former is more common in industry and is considered here. Factors which control the extent of the solids pollution problem include particle size distribution, density, and loading. For example, a heavy dust loading from a pulverized coal-fired boiler may be 2.0 grains per cubic foot. If the dust has a density of 2.5 and an average particle size of 10 microns, it represents 3500 ppm by volume. This low volume concentration makes it difficult to find an effective mechanism by which the dust particles can be selectively removed from a gas stream.

Brute force methods are often employed. Filtration is one method, for example, in which the gas passes through a porous media whose openings are too small to permit the passage of the solid dust. The size of the dust is a primary factor in this case. For small volumes of gas where pressure drop is not an important consideration, this is an effective and positive method.

A second property useful in gas cleaning is the inertia of the dust particles. Here the mobile gas molecules follow lines of flow which the dust particles cannot manage because of their greater inertia. Impingement filters, baffles, and centrifugal or cyclone separators are examples of dust collectors utilizing this property. In cases of this type the entire gas stream must follow the lines of flow and pressure drop is again important. Water scrubbers also depend on inertial contacting of the dust and the subsequent removal of the water droplets.

Precipitators depend on the difference in dielectric constant between the pollutants and the gas phase to charge the dust. The action of the electric field on the charged particles drives them out of the gas stream to a collecting surface. The dust is later removed from the collecting plates by controlled rapping so as to prevent re-entrainment of the dust to the main gas stream.

Precipitator Components

A precipitator has three main components, a discharge electrode to supply the initial source of high energy electrons useful in charging and precipitating the dust, an extended surface to collect and hold the dust, and a method of removing the precipitated dust to hoppers such as by rapping or irrigation. If we examine the discharge electrode we find the following factors are important:

1. Electrical properties.
2. Mechanical and thermal characteristics.
3. Corrosion resistance.
4. Electrode shape.
5. Ozone generation.

Electrical Properties

In an electrostatic precipitator a power supply impresses a high voltage, usually unfiltered dc, on the discharge electrode with collecting electrode grounded. Negative corona is formed as a self-maintaining gas discharge between the discharge electrode and the collecting plate and is initiated by positive ion bombardment or photoelectric emission of the discharge electrode surface. As a result electrons are emitted which are rapidly accelerated by the high voltage stress near the wire. The high energy electrons ionize the gas molecules by collision forming large numbers of positive ions and electrons. The positive ions move to discharge electrodes where they are neutralized and where they produce additional electrons. The electrons formed by the ionization of the gas rapidly move to the collecting electrode. In this region they do not have sufficient energy to continue ionization but are attached to gas molecules forming negative ions of lower mobility. The negative ions create a space charge which occupies most of the region between the electrodes and act so as to inhibit further ionization.

The electron emission from the discharge electrode is greatest at regions of low work function which in turn is effected by the condition of the metal surface. The discharge points are distributed sporadically along the surface of the wire with some spacing between them because of mutual space charge repulsion between the discharge points. The corona points move along the wire in an irregular fashion as the local work function of the surface changes.

To counteract the irregular distribution of discharge points, barbed electrodes have been used to fix the distribu-

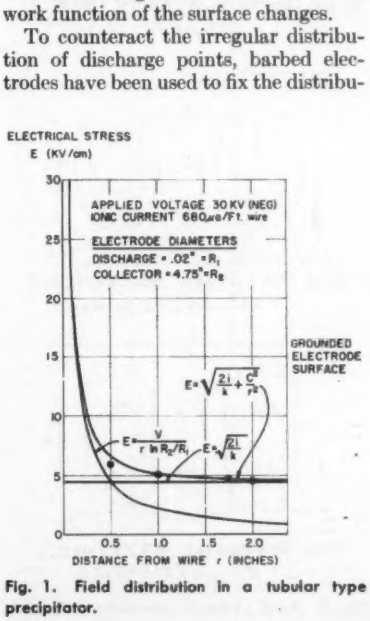

Fig. 1. Field distribution in a tubular type precipitator.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

tion of discharge glow points uniformly throughout the precipitator. The result has generally been an increased power input and an improved performance through a more uniform distribution of energy to the gas being cleaned.

The discharge electrode must also be a good electrical conductor since a current flow must be maintained and a large voltage drop cannot be tolerated in the discharge electrode assembly itself.

Mechanical Strength and Thermal Characteristics

Often running 20 feet or more in length, the discharge electrode is subject to a number of mechanical stresses. Of special importance are the fatigue characteristics of the material since forced vibrations occur from both the passage of the gas and the electrical ion bombardment on the wire. Vibrations will break the wires in areas where the stresses are greatest such as in regions where the wires enter the plate region. This has been overcome to a large extent by reinforcing the wires in this critical region with shrouds. The stiffer the wire the more susceptible the wire to fatigue. Scratches or sharp edges decrease the endurance limit. In installations where vibration is likely to be a problem, it is sometimes desirable to use a more flexible discharge electrode which has greater fatigue resistance than a stiffer larger diameter wire.

The discharge electrode assembly in heavy dust applications must be rapped to remove dust which accumulates on the electrodes over a period of time. Occasionally the dust may be sticky or have cementing properties which makes its removal difficult. The discharge electrodes must be capable of withstanding the rapping necessary to remove this type of deposit as well.

Some installations may operate in temperature cycles ranging from freezing temperatures to over 800°F. Through this wide temperature range the electrodes must be allowed to expand or contract without buckling. For this reason the electrodes are suspended at one end and allowed to grow to prevent buckling. Commonly the wires are individually weighted within a guide assembly to allow for changes in length with temperature. For example, a 20 foot discharge electrode of type 304 stainless steel will increase 1.4 inches in length between installation at 60°F and operation at 700°F. If rigidly fixed at both ends, the subsequent buckling can cause a misalignment which will reduce the sparking potential and the efficiency of the precipitator.

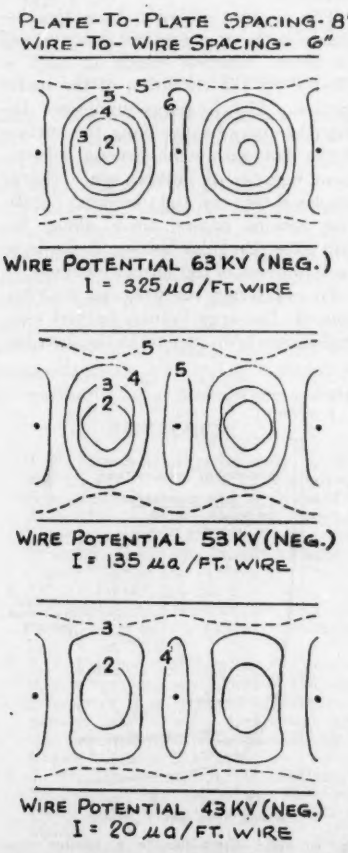
PLATE-TO-PLATE SPACING- 8"
WIRE-TO-WIRE SPACING- 6"
WIRE POTENTIAL 63 KV (NEG.)
I = 325 μa/FT. WIRE
WIRE POTENTIAL 53 KV (NEG.)
I = 135 μa/FT. WIRE
WIRE POTENTIAL 43 KV (NEG.)
I = 20 μa/FT. WIRE

Fig. 2. Field strength distribution (kv/cm).

Table I

Precipitator Application	Discharge Electrode Shape	Material of Construction	Wire Size (Effective)	Temp. °F	Comments
Acid mist	Star	Lead with monel core	3/8 in.	110	Wet recovery
Cement dust	Sharp point	Mild steel	3/4 in.	700	
Fly ash	Square	Mild steel	3/16 in.	290	
Home	Round	Tungsten	0.005 in.	70	Two-stage operation
Open hearth	Sharp point	Mild steel	3/4 in.	550	

Corrosion Resistance

The composition of the gas being cleaned, the nature of the dust, and the operating temperature determine the degree of corrosion which may occur. The discharge electrode must be made of materials to withstand the atmosphere. Mild steel is satisfactory in some applications but stainless steel, Hastelloy, lead, tungsten, titanium, and other exotic metals have been used. In acid mist recovery plants, lead covered wires with a monel core have been used successfully.

Electrode Shape

Discharge electrodes have been made having round, square, twisted square sections or with barbed points uniformly spaced. Star shaped electrodes have been used. Sharp-edged electrodes are generally preferred since they increase the formation of a corona discharge. Wires are generally straight to improve alignment although spiral electrodes which increase the total discharge surfaces are also used. A compromise between large diameter to give high mechanical strength and small diameter to reduce the corona starting voltage must always be made. Barb-edged electrodes have been successfully applied especially in applications where very fine particles are encountered.

The sharper the discharge electrode shape, the lower the voltage required to produce corona. Square cross section wires are frequently used as discharge electrodes rather than as round wires because their sharp edge enhances the initiation of corona. Table I shows a number of applications and the type of discharge electrode used.

Ozone Generation

In some applications, such as the cleaning of air for homes or offices, ozone and nitrous oxides must be kept at a minimum level and over-all concentration of less than 0.005 ppm is generally desirable. This is accomplished by using fine wires at positive polarity. Ozone is formed by high energy electron bombardment of oxygen molecules. By operating at positive polarity, positive ions predominate in all regions except immediately adjacent the discharge electrode. Positive operation produces roughly 1/7 as much ozone as negative operation. Using a small diameter discharge electrode allows lower operating voltages to be used which helps reduce ozone formation. Two-stage operation using plates to collect charged dust particles limit the corona formation and further reduce the total ozone and nitrous oxides formed.

For heavy industrial dust applications, negative polarity is preferred because higher voltages can be maintained resulting in increased precipitator efficiency.

Precipitator Efficiency

The performance of discharge electrodes can be evaluated on the basis of efficiency.

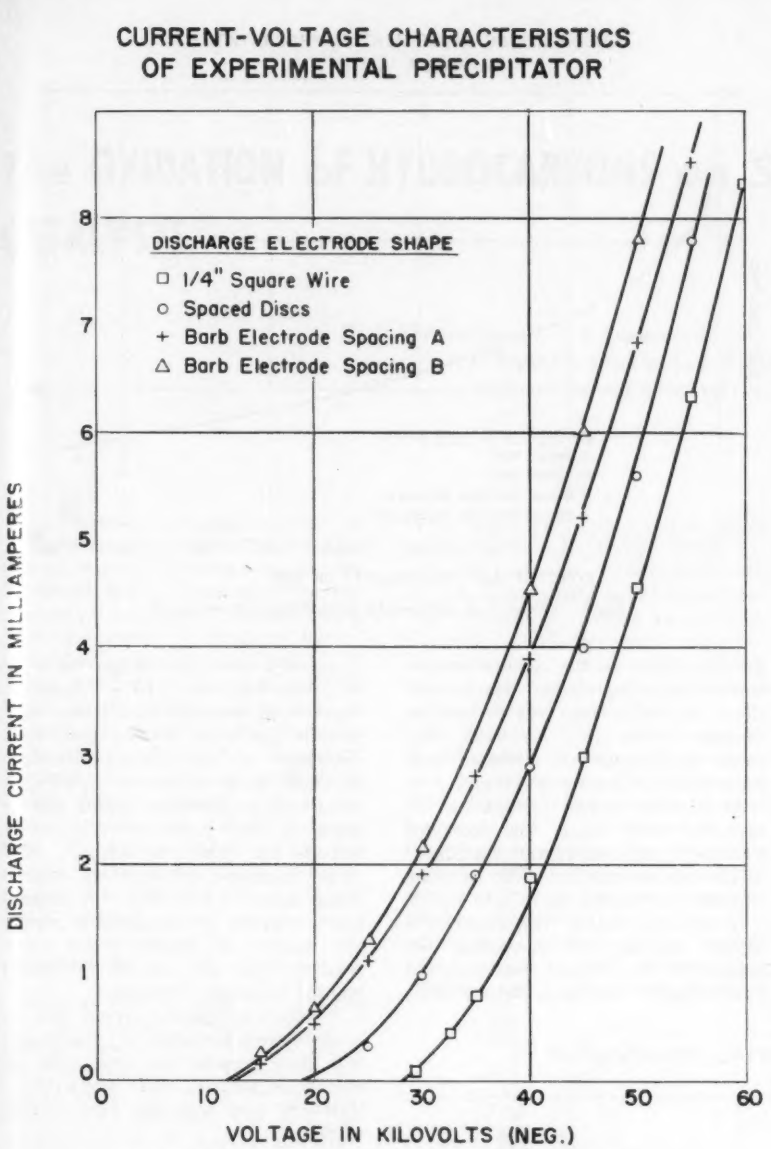

Fig. 3. Current-voltage characteristics of experimental precipitator.

The collection efficiency η of an electrostatic precipitator was theoretically developed by Deutsch[1] and as modified by White[2] is

$$\eta = 1 - e^{-(A\omega/V)}$$

where A is the effective collecting surface area, V is the gas flow rate, and ω a drift velocity constant.

The drift velocity constant, ω, depends on particle size, field strength, and gas composition.[2]

$$\omega = rE_0E_p/2\pi\theta$$

where r = particle radius; E_0 = charging field; E_p = precipitating field; and θ = gas viscosity.

A plate precipitator will have a length, l, height, h, and spacing, d. A given volume of gas, V, moving at a velocity, v, will be in the active region of the precipitator for a time, t.

The plate surface area can be written as $A = 2lh$.

The gas volume, V, is written as $V = hdv = hdl/v$.

As a first approximation, the precipitating field strength, E_p, is approximately equal to the charging field strength, E_0.

If we make the above substitutions the efficiency can be written as

$$\eta = 1 - e^{-(rtE_0^2)/(\pi d\theta)}$$

The three factors which are variable are field strength, E_0, time, t, and spacing, d. From economic considerations it is desirable to keep t at a minimum and d as large as possible. The field strength is the most readily adjustable variable. A small change in the field strength can have a profound effect on performance.

For tubular precipitators the field strength, E, near the collecting surface has been shown to be essentially[3]

$$E = \sqrt{2i/k}$$

where i is the current per unit length of wire and k is the ion mobility. This is shown as Fig. 1. For parallel plate precipitators the field strength is more complicated as shown in Fig. 2.[4]

In either case the field strength driving the charged particles from the gas near the collecting surface depends primarily on the discharge current. This effect of discharge electrode shape on current and thus the field strength and efficiency is compared with experimental results in the laboratory and in the field.

Current-Voltage Characteristics of Test Electrodes

Figure 3 compares the electric characteristics in air of four distinct discharge electrode shapes. It is seen that a higher current at a given voltage can be obtained with the sharp-point electrodes at a given voltage. The electrode shapes investigated are shown schematically in Fig. 4.

Laboratory Measurements

Figure 5 compares the efficiency of an experimental precipitator as a function of discharge electrode used. In all cases the tests were made at constant velocity with a suspension of fly ash dispersed in air. The effect of reentrainment was minimized by maintaining a continuous film of water on the collecting electrode to remove the dust as it was precipitated. Dust loadings

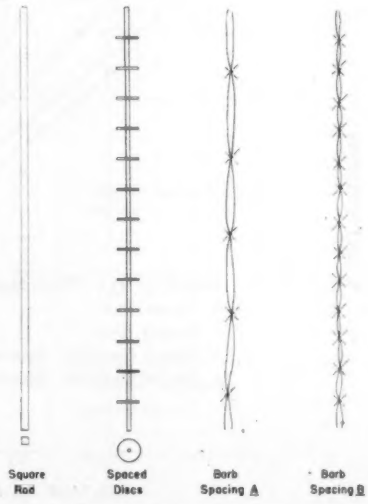

Fig. 4. Typical discharge electrode shapes.

were one to three grains/ft³.

Highest efficiencies were obtained with the barbed electrodes. Comparing the two types of barbed electrodes tested one finds that at a given voltage higher efficiencies were possible when using the electrode with the smaller spacing between barbs (i.e., greater total current increase).

Efficiency and Power Input

The data of Fig. 5 reduces to a single curve when plotted as input power (Fig. 6). Initially, a small power increase results in a large improvement in efficiency but as the more rapidly precipitable dust fraction is removed, a larger energy input is required to obtain a small improvement in efficiency. The data represent the apparent power impressed on the gas in the form of a corona discharge. While leakage current across the insulators is also included, additional experiments not reported here, show this to be slight.

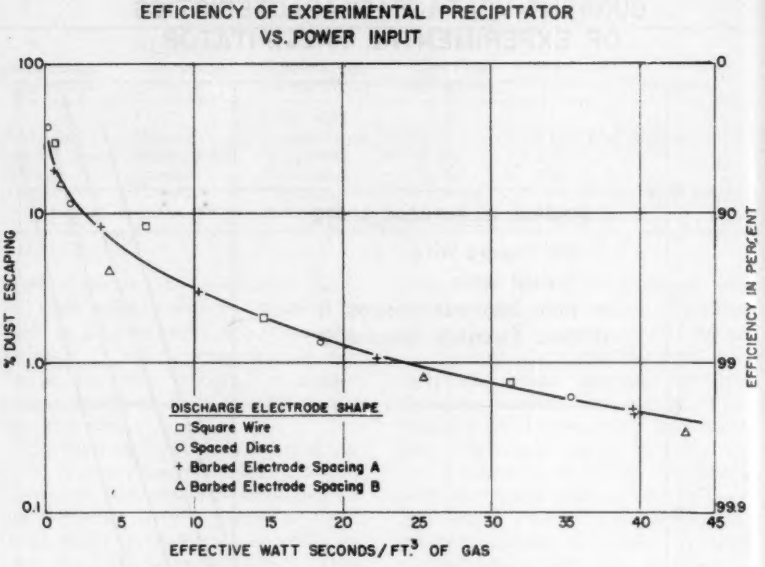

Fig. 6. Efficiency of experimental precipitator vs power input.

Field Experience

Recently, several commercial installations have been modified primarily by changing the discharge electrode shape.

In one instance a cement manufacturing installation was refurbished after having been originally put in service in 1912. This 47-year-old installation was still doing a remarkable job but the stack appearance was no longer acceptable by modern standards. The major alteration consisted in replacing the conventional discharge electrodes by sharp-pointed electrodes although improvements were also made simultaneously to the rapping system and the collecting plates. The over-all effect on performance was to increase efficiency from 76% to 93%. Apparent work input was increased from 2.1 to 11.3 watt seconds/ft.³ of gas.

At another cement installation the apparent work input was increased over four times from 5.8 watt seconds/ft³ to 25 watt seconds/ft³. The resulting efficiency increased from 76% to 96.6%.

In an open hearth dust application oxygen lancing and increasing the capacity of the furnaces resulted in the overloading of the precipitators. Efficiency fell from the design figure of 98% to less than 60%. Apparent input work was less than three watt seconds per cubic foot of gas. Substitutions of barb-pointed discharge electrode gave uniformly distributed point-to-plane discharge points and an apparent input power of over 13-watt seconds per cubic foot of gas. Efficiency increased well above the original design figure to over 98%. Additional power supplies were required to supply the increase in useable power which resulted from the use of the sharp pointed discharge electrodes.

A direct comparison could not be made between the laboratory results and field data because the field units all operate in the dry state where re-entrainment may limit the final over-all efficiency.

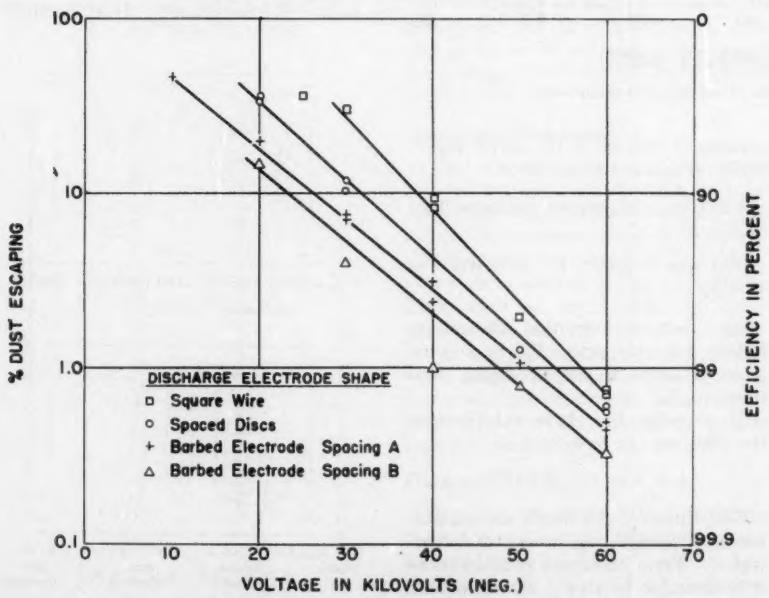

Fig. 5. Efficiency of experimental precipitator.

Summary

Discharge electrodes are made in many shapes and of different materials depending upon the application involved. Factors which must be considered include the type of dust, operating temperature, corrosion, and ozone generation. The efficiency of a precipitator is shown to depend on the total power input and is especially sensitive to the discharge current. Laboratory and field data verify the use of barbed discharge electrodes to improve precipitator efficiency.

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The OXIDATION of HYDROCARBONS on Simple Oxide CATALYSTS*

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Recently a large number of catalysts have been tested for the oxidation of various hydrocarbons at the Bureau of Mines Laboratories for the purpose of developing catalysts which may be suitable for oxidizing hydrocarbons in automobile exhaust gas.

The exhaust from automobiles is known to constitute a major form of atmospheric pollution and catalytic oxidatation in the muffler or exhaust manifold is a favored method of dealing with it. Present work at the Bureau is concerned with the development of suitable catalysts for the purpose. The study is being made in co-operation with the U. S. Public Health Service.

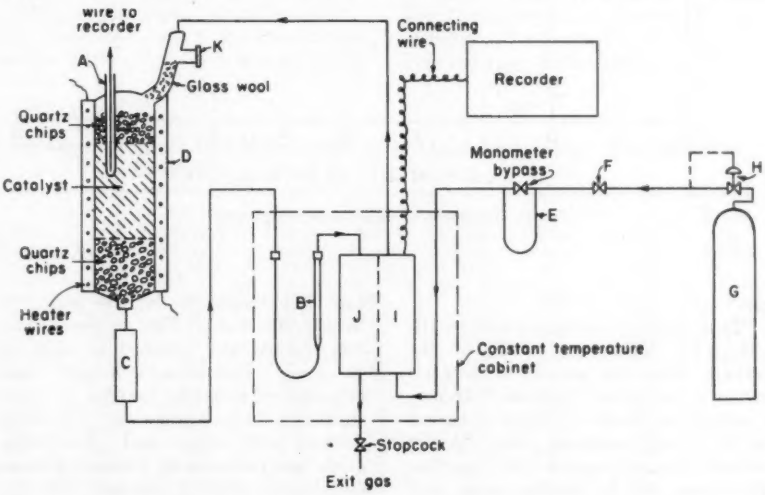
Experimental

Since a large number of catalysts were to be tested, a rapid method of testing was desirable. The microcatalytic-chromatographic technique appeared to be well suited for this purpose. This technique was first described by Emmett[1] and his coworkers and was used to study such catalytic reactions as cracking and polymerization of hydrocarbons.

The testing apparatus is shown schematically in Fig. 1. Oxygen is used as the carrier gas at a constant flow of 40 cubic centimeters per minute. The gas is passed through the flowmeter, then through the reference side of the thermal conductivity cell, and into the microcatalytic reactor. The reactor is made of quartz, and can be operated over the temperature range 100°C to 600°C. Heating is electrical and the temperature is controlled to ± 2°C by a Leeds and Northrup controller-recorder. The catalyst, about 5 cc in volume, is held in place by a layer of quartz chips at the bottom of the reactor. Additional quartz chips are placed at the top of the catalyst bed to aid in preheating the gas. Hydrocarbon samples (0.005 cc volume) are injected into the gas stream at the top of the reactor with a hypodermic needle and syringe. (Recently, a Fisher sample injection apparatus has been put into use by which hydrocarbons can be introduced with a calibrated micro-pipette.)

As the hydrocarbon passes through the catalyst bed, it may undergo oxidation, depending upon the temperature of the catalyst. The reaction products are swept out of the reactor by the carrier gas and pass first through a dryer containing anhydrous calcium sulfate and then into the chromatographic column. The column is a coiled 10-ft length of $^5/_{16}$-in. copper tubing containing 30 to 60 mesh celite (Fisher "Columpak") with 28% by weight of silicone oil added (Low Corning 550). The separated products are directed through the measuring side of the thermal conductivity cell and changes in conductivity are recorded in the conventional manner on a recording potentiometer. The cell is of the heated filament type manufactured by the Gow-Mac Corporation. Both the cell and the column are maintained at a constant temperature of 50°C for the C_5 hydrocarbons and 75° for C_6 hydrocarbons.

A group of eight hydrocarbons was selected for study, comprising: *n*-pentane, isopentane, pentene-2, pentyne-1, *n*-hexane, cyclohexane, 2,3-dimethylbutane, and benzene. These compounds were chosen so as to be representative of the types of hydrocarbons normally present in exhaust



A	Thermocouple well	G	Oxygen cylinder
B	Chromatographic column	H	Pressure regulator
C	Dryer	I	Reference cell
D	Insulated reactor (quartz)	J	Conductivity cell
E	Flowmeter	K	Serum cap for sample injection
F	Microvalve		

Fig. 1. Flowsheet of catalytic oxidation apparatus.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

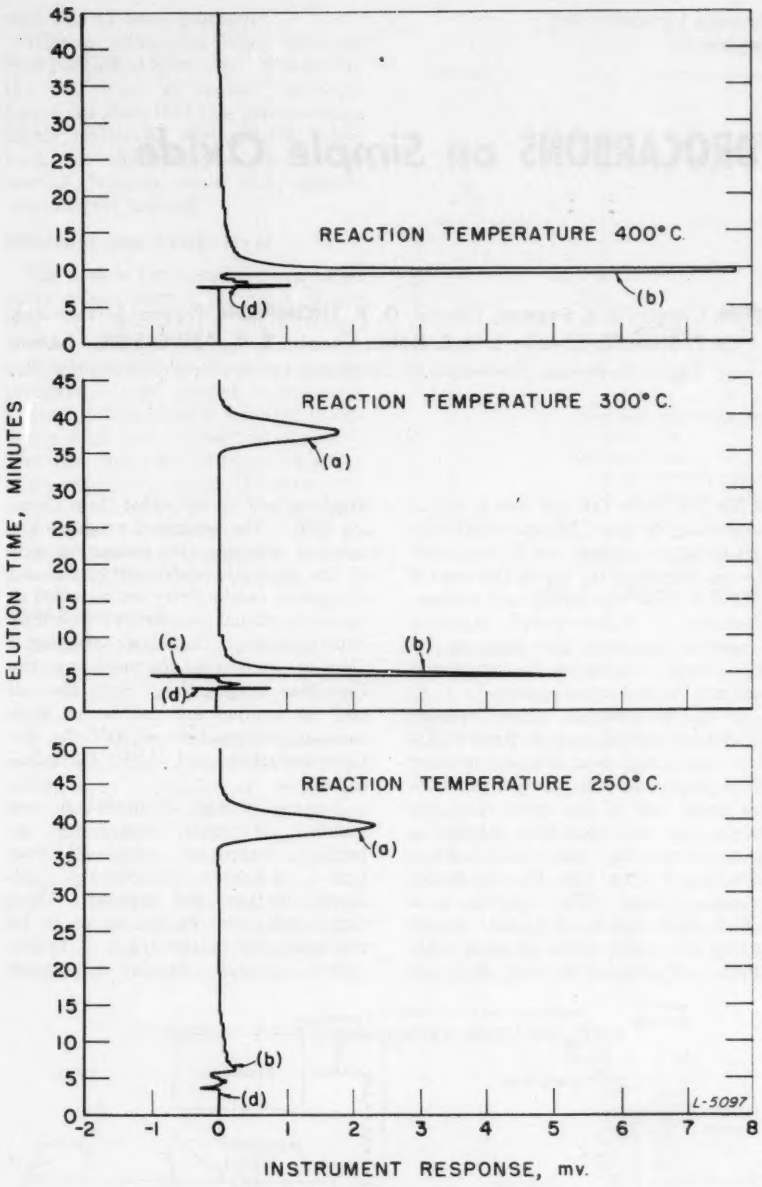


Fig. 2. Oxidation of benzene on ferric oxide.

gas.

Many oxides of metals of groups IB, VB, VIB, VIIB, and VIII of the periodic table are known to be good methane oxidation catalysts.[2] Hence, a survey of these materials appeared to be a likely starting point. A list selected from the oxides used, together with their B.E.T. surface areas and x-ray diffraction data is shown in Table I. Most of the metal oxides were prepared by precipitation from an aqueous solution of the nitrate by adding potassium carbonate solution. The precipitate was filtered, washed free of potassium salts, dried to form a cake, and finally sintered in air at 600°C as this temperature was chosen to be the limit for subsequent tests. The sintered cake was crushed and screened to eight to 12 mesh. Vanadium pentoxide was prepared in a similar manner by precipitation from ammonium vanadate solution with acetic acid. Zirconium oxide was prepared by thermal decomposition of zirconyl nitrate. The titanium oxide catalyst was made by pelleting analytical grade of Fisher titanium dioxide. The aluminum oxide listed in Table I was alumina catalyst AL-0104T obtained from the Harshaw Chemical Co. and the silica was "Santocel" silica aerogel from the Monsanto Chemical Co.

Some typical chromatograms obtained with the apparatus are shown in Fig. 2. These charts demonstrate the oxidation of benzene over ferric oxide at 250°, 300°, and 400°C. The peaks a, b, c, and d represent, respectively, the peaks for benzene, carbon dioxide, methane, and the disturbance of carrier gas flow due to injection of the sample. At 250°C, very little reaction has taken place. At 300°C, some oxidation has occurred, as shown by the carbon dioxide peak and the smaller peak from benzene. The presence of a small methane peak indicates that a slight amount of cracking has also taken place. At 400°C, the benzene has been completely destroyed.

Discussion of Results

Complete removal of all the hydrocarbons was not attained with some of the catalysts, even at 600°C. In other cases, the extent of oxidation was not a linear function of the temperature. And, as is often the case in catalytic chemistry, activities of these catalysts are not directly related to their surface areas. However, it will be seen that the most active catalysts have at least a moderate area. Because of these facts, comparison of activities was more convenient and meaningful if made on the basis of 80% decomposition of the hydrocarbons rather than on complete decomposition.

Table II lists the temperatures at which these catalysts caused 80% decomposition of each of the test hydrocarbons for all cases where this result was realized at temperatures no higher than 600°C. This table also shows the arithmetical average temperature required for the 80% decomposition and assigns numerical relative activities to the catalysts, the most active being numbered 1. Silver oxide could not be included in Table II because it was itself completely decomposed at 300°C, and at this temperature the maximum hydrocarbon decomposition observed was 60%, this being for benzene.

The data are presented in terms of the percentage disappearance of the parent peak of the test hydrocarbon. This does not mean that all of the hydrocarbon that has disappeared has been oxidized to carbon dioxide and water. In some cases, methane has been found as one of the products. As another example, when cyclohexane was passed over catalysts consisting of oxides of iron, zirconium, silicon, magnesium, molybdenum, vanadium, and zinc, benzene was produced under certain conditions. In still others, a process similar to chemisorption took place. This was characterized by the disappearance of the parent peaks from the chromatograms without the appearance of any new peaks corresponding either

Table I—Structural Properties of Oxide Catalysts

Catalyst No.	Oxide Formula[a]	Crystal Structure	Surface Area, m^2/g[b]
PH 21	Cr_2O_3	Corundum type	14.0
PH 24	αFe_2O_3	Hematite	13.9
PH 29	NiO	Bunsenite	6.2
PH 32	CuO	Tenorite	0.5
PH 34	Co_3O_4	Spinel type	11.3
PH 35	γMn_2O_3 + Mn_3O_4	X-ray powder data file 6-0540 / X-ray powder data file 2-0896	3.2
PH 47	ZnO	Zincite	0.5
PH 48	Pb_3O_4	Minium	0.6
PH 49	MgO	Periclase	90.3
PH 50	MoO_3	X-ray powder data file 5-0508	<0.1
PH 51	ThO_2	Thorianite	55.7
PH 54	CeO_2	Fluorite type	9.3
PH 64	Ag_2O	Cuprite type	0.5
PH 57	V_2O_5	X-ray powder data file 3-0206	1.0
PH 59	TiO_2	Anatase	10.2
PH 63	ZrO_2	Fluorite type	0.7
PH 66	WO_3	X-ray powder data file 5-0363	3.6
7013	γAl_2O_3	Spinel type	87.6
7018	SiO_2	Amorphous	421

[a] Most oxides were the same before and after use. Exceptions were pH 35 which was Mn_2O_3 and pH 48 which was PbO before use.
[b] Determined before use.

to combustion products or products of thermal decomposition. This phenomenon may be the result of adsorption, polymerization, or free carbon formation. It occurred at low temperatures, and was most frequently observed on the alumina supported catalysts and on alumina itself. On raising the catalyst temperature to about 500°C, the "adsorbed" material was removed as carbon dioxide as shown by the chromatograms.

Relative performance of the catalysts is also shown in Fig. 3 to 9 where the temperatures required for 80% reaction for two different hydrocarbons are plotted against each other. Plotting the data in this manner results in three significant characteristics: First, the catalysts will align in order of activity, with the most active in the lower left hand corner and the least active in the upper right. Second, specificity will be indicated if a catalyst lies significantly outside the general trend of the data. Third, general tendencies for a hydrocarbon to be more readily oxidized than the one with which it is being compared will be indicated by a grouping of all the data points toward one or the other axis.

In Fig. 3, the data for *n*-pentane and *n*-hexane are plotted against each other. The most active catalyst is cobalt oxide, followed by the oxides of chromium, iron, manganese, nickel, cerium, thorium, aluminum, and titanium. Next in order are the oxides of lead, magnesium, copper, zinc, tungsten, silicon, and zirconium, which are moderately active. The points lie in general along a curve which is closer to the *n*-pentane axis than the *n*-hexane axis indicating that for these experiments, n-pentane is more difficult to oxidize than *n*-hexane. This behavior is in accord with the frequently observed fact that reactivity generally increases with molecular weight in a given homologous series.

In Fig. 4, similar data for benzene and *n*-hexane are plotted. Cobalt oxide is again the best catalyst, followed by the oxides of manganese and nickel. Next, closely grouped are the oxides of chromium, iron, copper, titanium, cerium, thorium, and aluminum. Lead, tungsten, silicon, vanadium, zinc, and zirconium oxides are the least active of the lot. The general trend of this data shows that benzene is more difficult to oxidize than *n*-hexane. Copper oxide is somewhat specific in that it has a lower decomposition temperature for benzene than for hexane.

In Fig. 5, data are given for 2,3-dimethylbutane and *n*-hexane. Here the five most active catalysts are the oxides of cobalt, manganese, chromium, nickel, and iron. The next five are oxides of titanium, cerium, thorium, aluminum, and copper. The remainder are considerably less active. In this series, the trend shows that the highly branched 2,3-dimethylbutane is more difficult to oxidize than *n*-hexane.

In Fig. 6, benzene and cyclohexane are compared. The general order of activity of the catalysts is about the same as it is for benzene and *n*-hexane. Benzene is slightly more resistant toward oxidation than cyclohexane.

The next three figures show the data obtained with the C_5 hydrocarbons. In Fig. 7, the oxides are compared for the oxidation of *n*-pentane and pentyne-1. Pentyne-1 is undoubtedly the most

Table II—Temperature for 80 Percent Decomposition of Test Hydrocarbons in Oxidation Tests. Unsupported Catalysts

Prep. No.	Catalyst	Benzene (°C)	Cyclo-hexane (°C)	*n*-Hexane (°C)	2,3-Di-methyl-butane (°C)	Isopen-tane (°C)	Pen-tyne-1 (°C)	*n*-Pen-tane (°C)	Pen-tene-2 (°C)	Aver-age (°C)	Rela-tive Activ-ity
PH 21	Chromium oxide	337	265	287	290	285	275	295	235	284	4
PH 24	Iron oxide	345	297	330	297	417	190	285	322	310	5
PH 29a	Nickel oxide	270	275	285	295	340	205	330	255	282	3
PH 32	Copper oxide	317	340	382	412	490	278	470	387	384	10
PH 34	Cobalt oxide	163	152	185	203	245	217	187	180	191	1
PH 35	Manganese oxide	282	232	250	275	372	225	350	225	276	2
PH 47	Zinc oxide	>600	565	355	560	>600	495	525	545	538	16
PH 48	Lead oxide	495	444	366	500	530	342	475	495	456	13
PH 49	Magnesium oxide	—	425	355	480	595	300	485	532	453	11
PH 50	Molybdenum oxide	>600	>600	545	>600	>600	550	>600	575	>600	18
PH 51	Thorium oxide	390	290	345	365	397	232	365	365	344	8
PH 54	Cerium oxide	370	320	297	373	412	—	355	275	325	6
PH 57	Vanadium oxide	587	560	538	587	597	397	587	400	532	15
PH 59	Titanium oxide	365	287	265	355	475	217	410	310	335	7
PY 63	Zirconium oxide	>600	595	456	600	600	467	522	545	561	17
PH 66	Tungsten oxide	480	540	450	570	>600	230	490	270	454	12
7013	Aluminum oxide[a]	417	340	353	385	510	290	382	332	376	9
7018	Silica[b]	>600	500	420	515	565	412	535	450	500	14

[a] Harshaw Chemical Co.'s AL-0104T.
[b] Monsanto Chemical Co.'s Santocel.

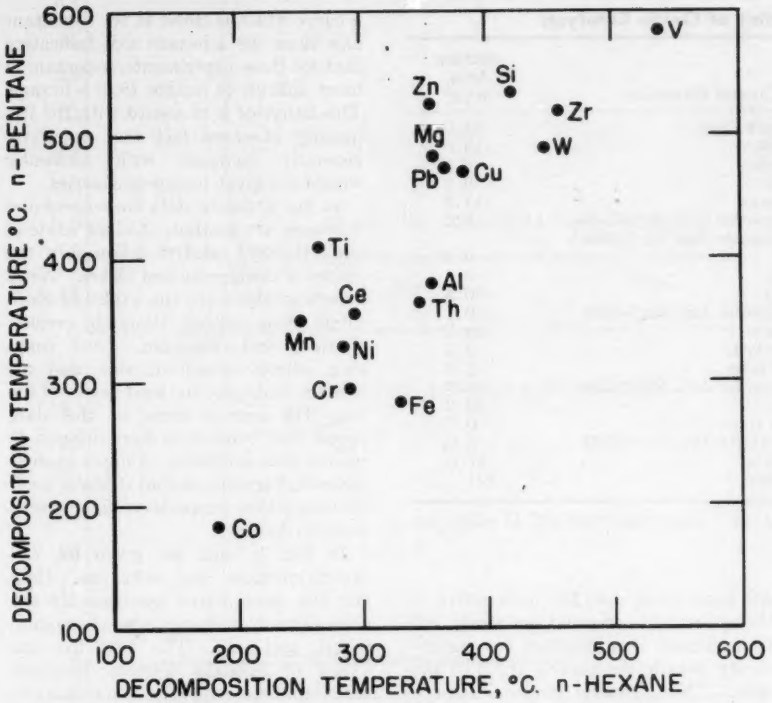


Fig. 3. Activity and specificity of various oxide catalyst for the oxidation of *n*-pentane compared with those for *n*-hexane (80%) reaction.

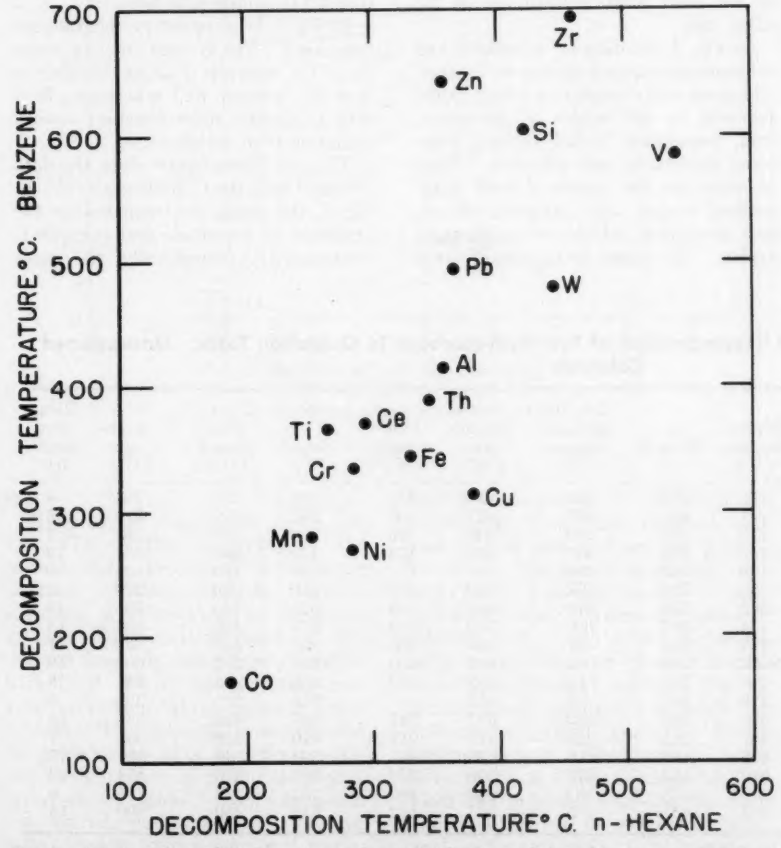


Fig. 4. Activity and specificity of various oxide catalyst for the oxidation of benzene compared with those for *n*-hexone (80% reaction).

easily oxidized hydrocarbon of the group. The oxides of iron, titanium, and tungsten are fairly specific toward pentyne-1. Cerium oxide (not shown) is also very specific, but the results are obscured because of adsorption on the catalyst below 200°C.

In Fig. 8, data are presented for the oxidation of pentene-2 and *n*-pentane. In this series the most active catalysts are the oxides of cobalt, chromium, manganese, nickel, cerium, and iron. The next most active are the oxides of tungsten, titanium, aluminum, thorium, and copper. The general trend of this series indicates that pentene-2 is more easily oxidized than *n*-pentane. Tungsten oxide stands out as being much more selective for oxidation of the olefin.

In Fig. 9, the oxidation of isopentane and *n*-pentane show that the most active catalysts are oxides of cobalt, chromium, nickel, manganese, thorium, iron, and cerium. Next are the oxides of titanium, aluminum, copper, and lead. In general, isopentane is more difficult to oxidize than *n*-pentane.

With the exception of silica and alumina, very few of the oxides that have been tested have enough physical strength to withstand the mechanical abuse or thermal shocks that would come to them if mounted in the exhuast system of an automotive vehicle. And, nearly all the more active oxides are expensive. It is therefore necessary to seek ways of supporting the active materials on carriers that will both act as bulking agents and provide the necessary strength to withstand the abuses of road service.

This problem has recently been given some exploratory attention. Based on the findings of the micro-tests on single oxides, supported catalysts were made containing cobalt, manganese, and chromium which were among the most active materials that had been tested. These were applied by impregnation-ignition procedures to a readily available commercial alumina that has the requisite mechanical properties and also has a high surface area (350 m^2/g). An alumina-supported vanadium oxide catalyst obtained from a commercial source was tested at the same time.

A resume of the results of these tests is contained in Table III. These data show that the activity of cobalt (compare with preparation PH 34, Table II) somehow suffered greatly in the process of being made into a supported catalyst. It was only a little more effective than the support. The most plausible reason for this behavior is that a reaction occurred between cobalt oxide and the support which formed an inactive complex. Preliminary x-ray examinations of both used and unused samples of this catalyst support this view.

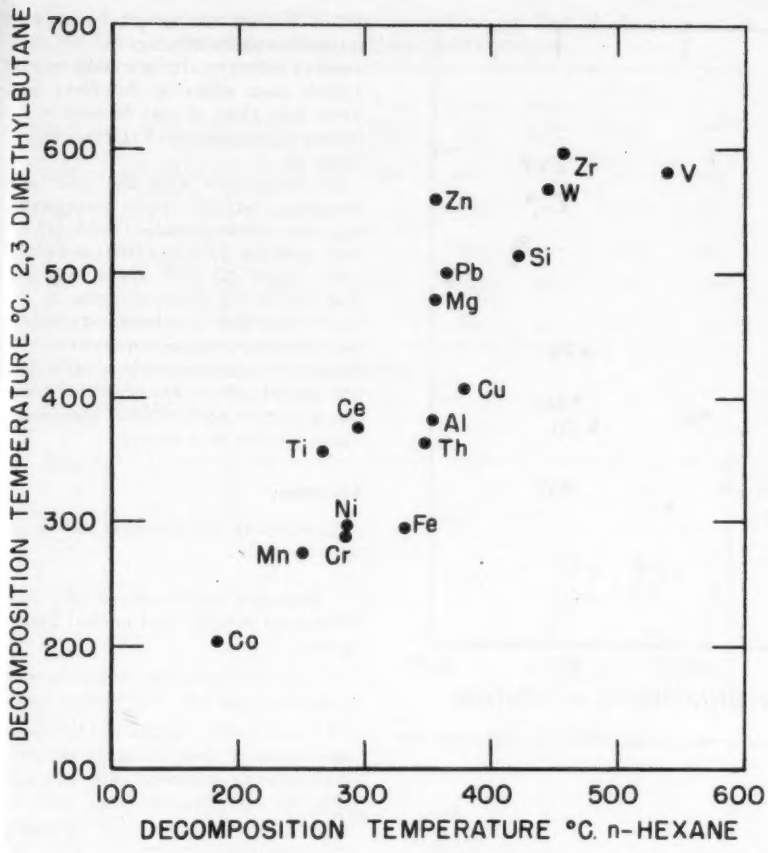


Fig. 5. Activity and specificity by various oxide catalyst for the oxidation of 2,3-dimethylbutane compared with those for *n*-hexane (80% reaction).

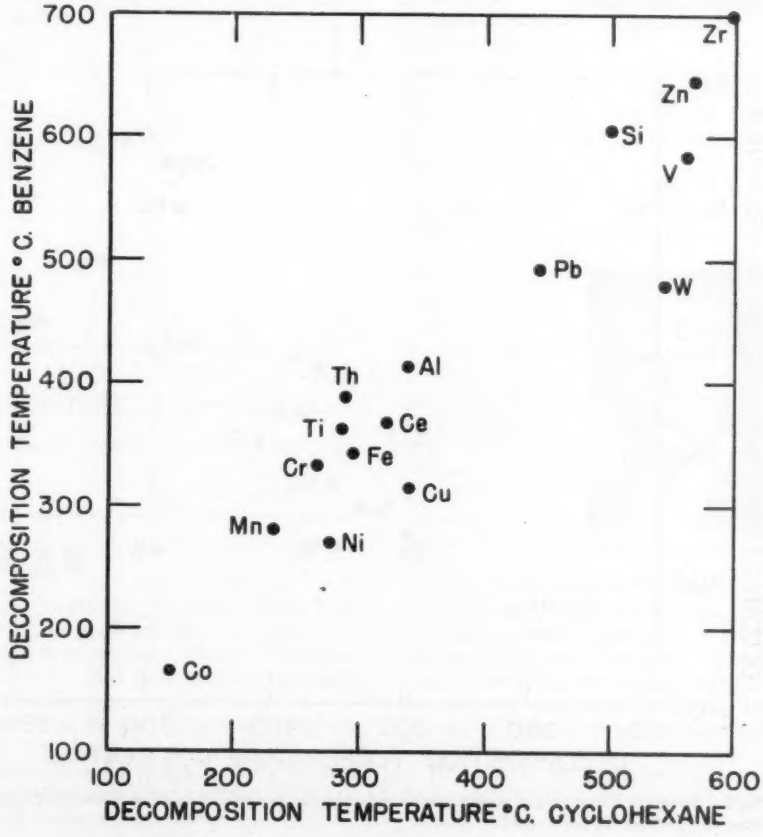


Fig. 6. Activity and specificity of various oxide catalyst for the oxidation of benzene compared with those for cyclohexane (80% reaction).

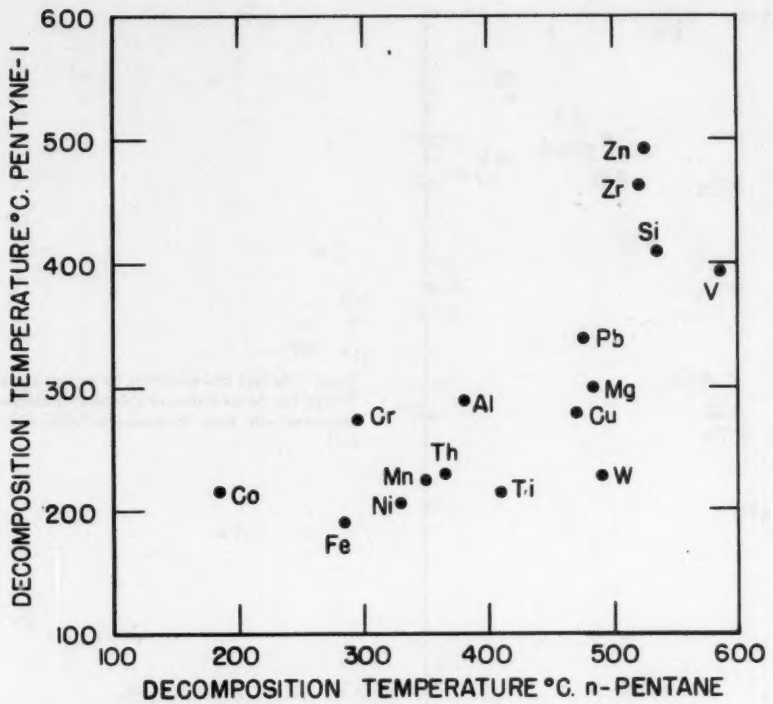


Fig. 7. Activity and specificity of various oxide catalyst for the oxidation of pentyne-1 compared with those of n-pentane (80% reaction).

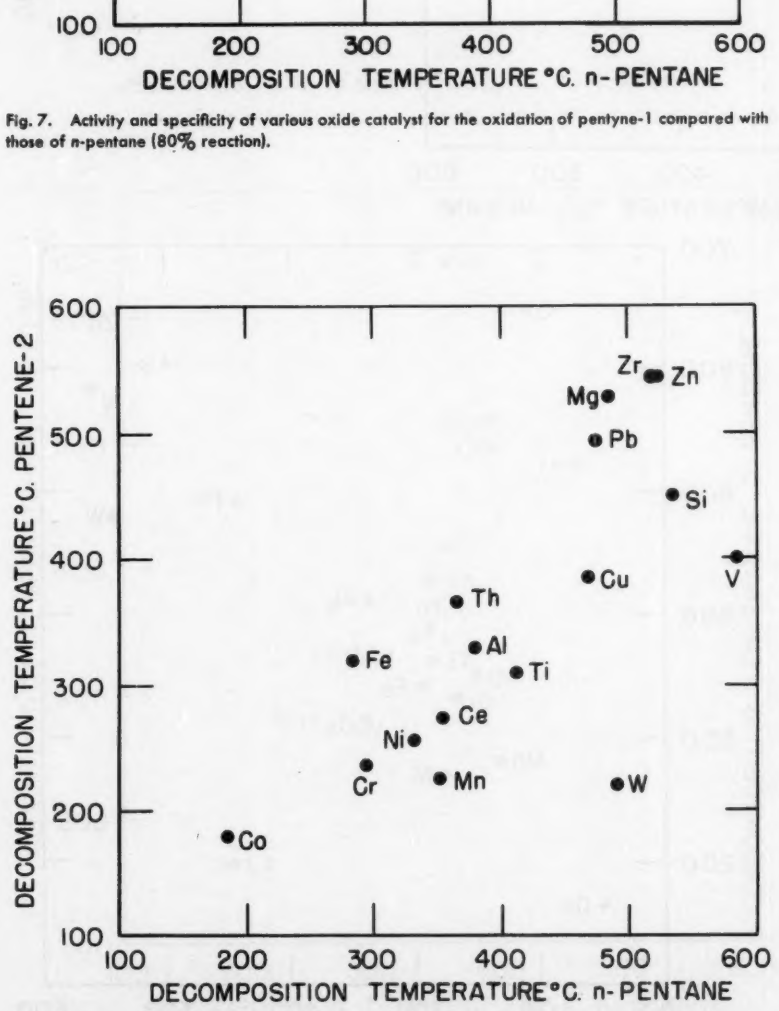


Fig. 8. Activity and specificity of various oxide catalyst for the oxidation of pentene-2 compared with those of n-pertane (80% reaction).

In contrast to cobalt, supported manganese and chromium did not show a loss of activity. In fact, both seemed a little more active in this form than when used alone as may be seen by referring to preparations PH 21 and 35 of Table II.

In comparison with the poor performance obtained from precipitated vanadium oxide granules (Table II) the high activity of supported vanadium oxide shown in Table III is startling. The reason for this difference in behavior has not yet been established. Nevertheless volume for volume the supported vanadium oxide catalyst does not exceed either the supported chromium oxide or the supported manganese oxide catalyst in activity.

Summary

In summary, the following statements may be made:

1 Branched hydrocarbons are more difficult to oxidize than normal hydrocarbons.

2 Ease of oxidation increases with molecular weight in homologous series.

3 Unsaturated aliphatic hydrocarbons are more easily oxidized than the corresponding paraffins, and susceptibility to oxidation increases with increasing unsaturation. For example, acetylenes are more reactive than olefins.

4 In comparing open chain and cyclic compounds having the same number of carbon atoms, reactivity toward oxidation probably decreases according to the sequence:

5 The most active single oxide catalysts were found to be the oxides of cobalt, nickel, manganese, chromium, cerium, titanium, and iron. It is conceivable that different forms or preparations of the same oxide would have different activities. Impregnating these oxides on various supports may also produce large changes in activity.

6 The microcatalytic - chromatographic technique has proved to be a very convenient means for rapid screening in oxidation studies. It is to be recommended where a large number of catalysts or reactants are to be investigated or where a wide range of temperatures is to be used.

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(Continued on next page)

Table III—Temperature for 80% Decomposition of Test Hydrocarbons in Oxidation Tests. Supported Catalysts

Prep. No.	Nominal Catalyst Composition	Pentene-2 (°C)	Isopentane (°C)	Benzene (°C)	2,3-Dimethylbutane (°C)	Av. Temp. (°C)
PH 100	10% Manganese oxide on alumina #H-151[a]	225	265	275	270	258
PH 95	10% chromium oxide on alumina #H-151[a]	—	270[b]	290	270[b]	277
PH 86	10% cobalt oxide on alumina #H-151[a]	—	355	445	370[b]	390
PH 27	10% vanadium oxide on γ alumina[c]	270[b]	310[b]	320[b]	320[b]	305
PH 77	Alumina #H-151	—	405	485	420[b]	437

[a] Supplied by Aluminum Company of America.
[b] Approximated value.
[c] Commercial catalyst.

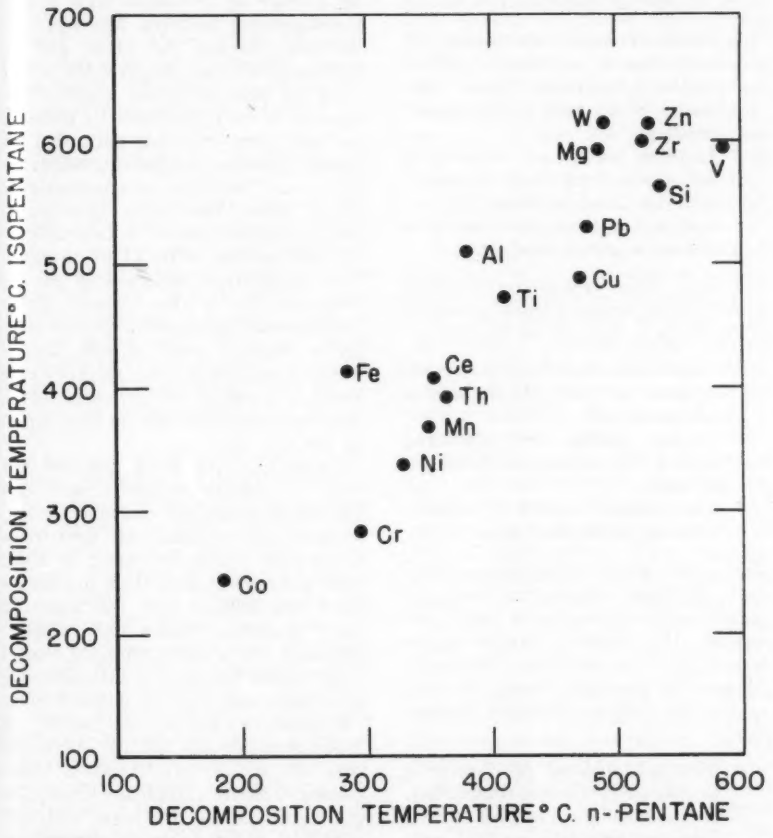

Fig. 9. Activity and specificity of various oxide catalysts for the oxidation of isopentane compared with those of *n*-pentane (80% reaction).

CALENDAR

Aug. 28–Sept. 2	Eighth International Symposium on Combustion, California Institute of Technology, Pasadena, California
Sept. 22–23	East Central Section Annual Meeting, Detroit, Michigan
Oct. 20–21	West Coast Section from Technical Meeting, Biltmore Hotel, Santa Barbara, California
Nov. 17	Mid-Atlantic States Section Meeting, Consolidated Edison Company, New York, New York
Dec. 3	Sixth Industrial Hygiene and Air Pollution Conference on New Environmental Problems in The Construction Industry, The University of Texas, Austin, Texas

General Retires; Mellon New Head

The retirement of General Matthew B. Ridgway as Chairman and Chief Executive Officer of Mellon Institute has been announced following the annual meeting of its Board of Trustees. Paul Mellon was elected Chairman succeeding General Ridgway, who was re-elected a Trustee and who will serve as a consultant to the Institute.

General Ridgway, who became 65 this year, joined Mellon Institute in September, 1955, following his retirement as Chief of Staff, United States Army.

Paul Mellon, the son of the late Andrew W. Mellon, one of the founders of the Institute, is a member of the Board of Governors of T. Mellon and Sons, Pittsburgh. He was recently elected a director of Mellon National Bank and Trust Company. He resides in Upperville, Va., and maintains an office in Washington, D. C. Mr. Mellon has been a Trustee of Mellon Institute for some years, and is also a member of the board of the National Gallery of Art, Washington, D. C. During World War II, Mr. Mellon served overseas as a major in the OSS.

Paul Mellon

General Ridgway, who came to Mellon Institute after a long and distinguished career as a military leader, lent his well-known vigor to advancement of the Institute's new fundamental research program. During his service as chairman, the program grew rapidly and is now well on its way to being a major part of the Institute's activity.

Matthew B. Ridgeway

Other administrative changes also were announced following the Institute Trustees' meeting. Howard C. Davies, Mellon Institute Treasurer, retired after 39 years as a member of the staff. Mr. Davies has been succeeded by George O. Luster, formerly Assistant Treasurer.

Mr. Davies has been re-elected as treasurer of APCA for the 10th succeeding year.

WHY *Industry Needs* PERFORMANCE STANDARD ZONING*

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Within the next 20 years half of our existing manufacturing capacity will be replaced by new plants. Practically all of these new plants will be built at the present periphery of our metropolitan areas. Land for this industrial growth must be reserved, through zoning, well in advance of the need. Industry should be provided with a choice of the most efficient and attractive sites in each of our metropolitan regions. Land use zoning with performance standards is one of the tools necessary to accomplish this goal. Performance controls, no matter how preliminary in form are needed now to help overcome prejudices against industry and to insure good locations for future industrial plants. These zoning controls are required to guide the development of open land in the suburbs—suburbs which still lack the protection of an air pollution agency. While the ultimate goal should be a region-wide air pollution program, industrial growth will not wait until the regional organization is established. The use of performance standards in a zoning ordinance, therefore, is an interim, but a very necessary measure to protect vacant land for future industry.

Trends in Industrial Land Use

Before proposing further land use controls on industry, it is logical to observe trends indicated by the newest factories. Frankly, industry is building new plants with far better space standards than zoning ordinances have ever required, or planners have ever anticipated. Therefore, it is reasonable to assume that most industry is working toward, rather than against the planner's goal of an efficient and harmonious living environment.

Eight trends in industrial land use are significant to the prevention of air pollution and to the protection of land for future industry; four of these trends result directly from industrial management decisions, and should guarantee the compatibility of future plants:

1. Industrial land requirements are increasing at a geometric rate.
2. Industry is seeking "front" sites rather than "back of the track" locations.
3. Industry wants to protect its new plants from "bad neighbors" and "bad neighborhoods."
4. Industry is trying to avoid congestion at its new location.

The next three trends in surburban growth could seriously handicap industry's efforts to improve its location:

5. Good industrial land is in extremely short supply in metropolitan areas.
6. Citizen protests are increasing against the zoning of land for industry.
7. Sites uniquely suited to industry are being lost to other uses.

The eighth trend in suburban growth best illustrates the critical need for performance standards in land use zoning. Dr. Leonard Greenburg referred to it in his New President's Message to the 52nd Annual Meeting of the Air Pollution Control Association:

8. Metropolitan areas are beginning to coalesce into a vast conurbation or megalopolis. The open spaces between urban regions will soon be encircled.

Let us examine the effects of these trends upon our mutual goal, an efficient and compatible living environment.

1. *Industry's Increasing Land Needs*

In less than two decades the land requirements of new industrial plants have increased two, five, 10, and even 20-fold. Before World War II, the great majority of factories had sites under 25 acres. Only a few industries, such as chemical works, refineries, or steel mills required sites of 100 acres or more.

New plants built during World War II, however, were considerably larger. In a study of 220 plants built as war manufacturing facilities, 24% had sites between 100 and 500 acres, and an additional 5% had sites over 500 acres.[1]

In the past five years, however, the amount of land purchased by industry for new plant sites has multiplied far beyond the most optimistic estimates. All types of industries have been seeking larger sites. Electronics laboratories and production plants, which used to be well satisfied with 10 to 15 acres, have found that 50-acre sites can be outgrown in a few years. Texas Instruments Incorporated recently built on a 500-acre tract outside Dallas. While this may be a Texan's idea of elbow room, it is safe to estimate that future electronics facilities will be built on 50 to 150 acre sites.

Large sites are being acquired not only by defense industries, but also by plants producing consumer goods. Johnson and Johnson sold three relatively new plants, averaging 30 acres each and consolidated these operations on a new 300-acre site—300 acres for baby products, plaster mill, surgical dressings, and a central shipping center. Ford Motor Company's automatic engine block and foundry installation in Cleveland is almost 500 acres. A major glass company recently purchased over 800 acreas near Stockton, Calif. General Electric's Appliance Park outside Louisville has 1000 acres, with 200 of these devoted to an arboretum. And then there are the very large heavy industries: United States Steel Company's Fairless Works, with 4000 acres; and the Tidewater Oil refinery on the Delaware River with almost 5000 acres.

The usual reasons for acquiring additional land—expansion, off-street parking and loading, the amentities of outdoor recreation, and some landscaping—could all be satisfied with far less land than industry is acquiring today. What is happening is that industry is buying protection, providing large buffer areas on all sides of the plant. In the past, industry has had more than its

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

share of neighborhood protests, and law suits. Management now reasons that space, rather than fences, makes good neighbors. Another reason for these large buffers is that many industries do not want another industry as a neighbor. They would rather have residences develop at the edge of their grass lawn.

These spacious buffers should take care of most of the usual complaints against industry: noise, vibration, glare, and, to some degree, traffic. The air pollution expert will have to evaluate extent to which landscaped or forested buffers can substantially reduce air pollution.

One thing is certain: the amount of land which industry thinks it needs for its new plants cannot be provided in the central cities. Therefore, the air pollution standards for these new plants need not be degraded to accommodate the obsolete plants of the old city.

2. *Industry's Desire for "Front" Sites*

Since the early 1950's industry has shown a distinct location trend toward "front" sites along new highways. In the past industry was relegated to the land "left over" after the choice tracts had been assigned to housing, commercial or public uses. However, "back of the tracks," "the wrong side of town," or next to the city dump is no longer acceptable for multi-million dollar investment.

There are practical reasons for industry's insistence upon a highway site.[2] The new superhighways allow considerable latitude in plant location. The labor market has been widened by several counties. Substantial savings in transport and storage costs are possible. The market area that can be economically served from one plant can be extended to include several metropolitan regions.

But industry's interest in front sites also helps assure both the air pollution officer and the city planner of a cleaner plant environment. Management is well aware of the advertising value of a clean and handsome plant, seen daily by thousands of customers, potential employees, and future investors. Some companies have placed a specific dollar and cents rating on a highway site, increasing their construction budget on a per capita basis for the number of people who will pass the plant in the next 10 years. Carling's Ale so selected its new brewery site on the Baltimore Beltway. Any company that is asking to be seen, is obviously not asking for trouble. Management must be certain that these plants can pass the public's test of no noise, no odor, and no black smoke.

Several new highways are attracting new industries: Route 128, the circumferential outside Boston, the Dallas Central Expressway, and the Schuylkill Expressway in Philadelphia, to name a few. Even toll roads: the New York Thruway, and the Pennsylvania and New Jersey Turnpikes are attracting major firms. Although most of the new construction is laboratories, warehouses, and light manufacturing, heavy industry is also seeking front sites. Owens-Corning Fiberglas Corporation's plant, the Phelps-Dodge new tube mill, and Alcoa's aluminum forge are fronting on the New Jersey Turnpike.

3. *Industry's Fear of "Bad Neighbors" and a "Bad Neighborhood"*

The wide landscaped buffers provided around many new plants were intended to protect the company from complaining neighbors. Usually the buffer also represented wishful thinking on management's part that this landscaping would protect the plant from the blighting influence of future "bad neighbors" namely: shoddy commercial developments, potential slum housing, or irresponsible industrial plants.

Industry has reason to fear future blight at the boundary lines of its new plants. Past planning and zoning practices have done little to protect its investment. Blighted neighborhoods have contributed to the flight of industries to the suburbs. Last year the author inspected fifty new plants in eighteen states which had recently moved from an old central city location to a new suburban site. During personal interviews, company officials emphasized the economic and social handicaps of their former urban locations. Plants in run-down neighborhoods were subject to extensive burglarism and vandalism. Firms had to hire additional watchmen to protect plant property. Employees on night shifts needed police protection for even a two-block walk to public transportation. Employee morale was affected by old plant facilities. The run-down appearance of neighboring buildings was hardly conducive to capital investment in plant rehabilitation. When the plant was surrounded by slum housing, the company was blamed for depreciation of the neighborhood, even though the plant was there before the houses were built.

Performance standard zoning, supplemented by a positive rather than negative land use planning for industry, can prevent the blight which industry fears at its new locations. Industry is becoming aware of the protection that zoning can provide. Recently the author inspected the newest plant of a large manufacturer whose products are in every household. The vice president in charge of manufacturing was quite proud of the several hundred acre site, beautifully landscaped, with plenty of room for expansion. Despite the large buffer area, however, he was still disturbed about future neighbors. He had just bought an additional 27 acres next to the new plant to prevent an asphalt batch plant from locating there. He had also acquired considerable road frontage directly across a four-lane but not limited access highway, to prevent cheap roadside commercial uses from being built opposite the front entrance of the plant. His worry now is that the Township will be too slow in passing their proposed new zoning ordinance which will provide performance standards. He feels strongly that these standards can prevent shoddy development near the plant. As the custodian of a large investment for the shareholders of his company, he wants the protection of high standards in industrial zoning.

4. *Industry's Fear of Congestion*

The unbroken belt of industries strung along the railroads, so characteristic of past industrial development, will not be repeated in the new pattern of industrial growth.

Large plants are beginning to avoid locations near other large plants. The inadequacy of roads at the change of shifts, the excessive demand on water and sewer lines, and now the concern about combined air pollution problems are causing many firms to sell even recently built plants that have since acquired too many industrial neighbors. New locations are selected in the hope that residences rather than new large employment centers will develop nearby.

Thus management decisions rather than public planning action are bringing about a more rational distribution of industrial activity throughout the metropolitan region. This interspersing of industrial plants and homes, however, even with generous use of space, requires zoning standards to protect both the industry and the neighborhood.

The next three trends in suburban growth could seriously handicap the compatible development of new industry.

5. *Shortage of Industrial Land*

The rapid rise in industry's land needs has not been paralleled by the reservation of land for future industrial growth. One reason for this lag has been a lack of knowledge, until recently, of industry's increasing space requirements.

In the late 1940's one of our important industrial regions estimated how much land it would require for industrial growth for the following 25 years. Ten years, and scores of new industries later, a check was made of the amount of land occupied by industry. In this 10-

year period, the region had used all of the industrial land that was thought would last for 25 years of growth.

The Baltimore Regional Planning Council, composed of the planning commissions and legislative bodies of the City of Baltimore and four adjacent counties, has just completed a sketch land use plan for the year 1980.[3] At the beginning of the study, approximately 40,000 acres were already zoned for industry. Since much of this acreage was still vacant, the major industrial land problem appeared to be a shifting of some of the industrial zoning from poor sites to locations better served by the proposed regional highway network. At first no major additions to the total amount of land zoned industrial were contemplated. At the end of the study, however, it was recommended that 20,000 additional acres be reserved for new industry and for the modernization of existing plants.

6. *Citizens' Protests Against Industrial Zoning*

Another reason for the short supply of industrial land is the extremely vocal citizen reaction against any proposal to zone land for industrial use. The citizens protest, and with some justification, that the zoning ordinance lacks standards to insure them that industry will be a good neighbor. Some citizens will always oppose any change. Others, however, recognize that industry and the suburban community must learn to live together. Such citizens groups are now proposing that land use controls be expanded to insure a clean industrial operation which will not endanger the health or well being of the town. These citizens are asking for performance standard zoning now, so that new industrial growth can be planned for, recruited, and protected.

Many citizens organizations are using the pamphlets of the National Industrial Zoning Committee in an educational effort to improve industrial zoning and planning practices in their communities.[4] The National Industrial Zoning Committee is a non-profit organization established to give particular study to problems of industrial zoning and to publicize its findings. The N.I.Z.C. is made up of representatives from seven nation-wide professional organizations: American Society of Planning Officials, American Industrial Development Council, American Institute of Planners, American Railway Development Association, American Society of Civil Engineers, Association of State Planning and Development Agencies, and the Society of Industrial Realtors.

7. *Loss of Unique Industrial Sites to Other Uses*

Theoretically, good industrial sites lost in one section of the region through citizen protest, can be replaced by land in another part of the region. Some sites, however, have unique location advantages which cannot be duplicated. This is particularly true of land fronting on deep water. Our increasing dependence upon foreign sources of raw materials, and the ever deepening draft of oil tankers, ore carriers, and other bulk vessels, make it imperative that land near deep water be reserved for industries dependent upon deep water transportation—as a matter of national interest. However, most of the waterfront on the Eastern seaboard is interspersed with small land holdings for summer cottages. Only a few sites of 1000 acres or more are still intact. These sites should be immediately zoned for industry. But the resistance of adjacent small property owners will be strong and loud. Performance standard zoning, to insure compatible development, could be a major key to citizen support.

8. *The Merging of Metropolitan Regions*

Finally, the most important reason for performance standards in industrial zoning is the coalescing of our metropolitan regions. Most industry will continue to be oriented toward population centers. Suburban towns can, for the next few years, continue to resist industry's expansion, pushing it farther out in the open areas. But shortly after industry has built beyond the present suburbs, new suburbs will be moving toward, and then beyond the new industrial plants. Soon the outer edges of metropolitan regions will merge, and the interstices will have disappeared under the final wave of suburbanization. A rational plan for industrial growth can be achieved at each stage of urban expansion, if we put into use standards now available to insure compatible development.

The future location pattern for industry is being determined now, too often through default. But wherever long-range planning for land use is being encouraged by local officials, citizens organizations, and industry—there the planners are seeking the aid of the air pollution experts. Standards formulated now to guide new industrial growth can be a major preventive measure, until the time when the whole region is protected by a full-scale air control agency.

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(*Continued on p. 343*)

Welcome New Members

SUSTAINING MEMBERS

Continental Oil Company
Houston, Texas

COMPANY MEMBERS

Air Pollution Control Society
Vancouver, B. C., Canada

Albany Felt Company
Albany, New York

British Belting & Asbestos, Ltd.
Cleckheaton, Yorkshire, England

Kellogg Mann Corporation
Buffalo, New York

Prenco Products, Incorporated
Royal Oak, Michigan

The Silent Glow Oil Burner Corporation
Hartford, Connecticut

West Virginia Pulp and Paper Company
Williamsburg, Pennsylvania

Richter Incinerator, Inc.
Minneapolis, Minnesota

United States Incinerator Corp.
Needham Heights, Massachusetts

INDIVIDUAL MEMBERS

Andrews, David B.
Pittsburgh, Pennsylvania

Barkhall, Harold W.
Cincinnati, Ohio

Beale, Leonard T.
Penllyn, Pennsylvania

Brady, John P.
Newark, New Jersey

Blanchard, Gerard E.
Albany, New York

Blum, Joseph K.
New York, New York

Bradley, William E.
Brea, California

Branscomb, Ben V.
Birmingham, Alabama

Brennan, John W.
New York, New York

Call, Richard A.
Provo, Utah

Campbell, Henry
Kingston, Rhode Island

Ciapetta, Frank G.
Clarksville, Maryland

Cummins, Cyril J.
Sydney, New South Wales, Australia

Cusumano, Robert D.
Mineola, New York

Darley, Ellis F.
Riverside, California

Dean, John G.
Wilton, Connecticut

Dennis, Richard
Boston, Massachusetts

Drowley, W. B.
Oakville, Ontario, Canada

Dull, William M.
Detroit, Michigan

Dupas, Robert
Port Jerome (Seine Maritime), France

Durrell, John H.
Cincinnati, Ohio

Eggett, Matthew G.
Los Angeles, California

Estes, Frances L.
Houston, Texas

Farber, Seymour M.
San Francisco, California

Flipse, M. Jay
Miami, Florida

Frank, Sidney R.
Goleta, California

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The ESTIMATION of AIR POLLUTION EMISSIONS in a REGIONAL Air Pollution Control DISTRICT*

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Any agency set up for the purpose of study and control of air pollution in a geographical area of jurisdiction must sooner or later estimate the amounts of various air pollutants emitted from the major sources within this area. A survey designed to develop these estimates can range from the relatively simple to the complex depending upon the variety and magnitude of sources, the geographical area covered, the pertinent meteorological variables and many other factors including available time and money.

Purpose of Survey Description

The air pollution situation in the San Francisco Bay Area represents the more complex end of this spectrum. This paper describes the methods used by the Bay Area Pollution Control District in estimating emissions from air pollution sources within its area of jurisdiction.[1] Other than the emission data for the Bay Area District little new information is presented. However, it was felt that the approach and methods used and the extensive bibliography would be of interest and use to other agencies confronted with the task of assessing the extent of an air pollution problem covering definite geographical boundaries.

Bay Area Air Pollution Control District

As background a short description of the Bay Area Pollution Control District is needed to point up some of the basic reasons for the approach and methods used in the survey described.

The Bay Area Air Pollution Control District was established by law in 1955[2]; the initiation of activity and the building of a sufficient technical staff were fairly well accomplished by the Spring of 1958. The District's major differences from other air pollution agencies are: (*a*) that it is the first multi-county agency in the United States (six counties comprising 4200 square miles), (*b*) its regulations are limited by law to performance requirements, rather than design standards, and (*c*) its enforcement of regulations depends upon an injunctive proceeding rather than misdemeanor and criminal action as in almost every other air pollution control agency in the United States.

The effects of excessive air pollution in the Bay Area were noted as early as 1951. Even as late as 1955, when the law establishing the District was adopted, no estimates had been made of air pollution emissions within this area.[3] Because of this lack of knowledge and the determination to fit the air pollution control program to the needs of the District, it was apparent that the technical staff should lose no time in making a survey of emissions.

Compromise of Total Knowledge

A technical man's retort to a request for a total air pollution emissions survey requiring accuracy and a minimum of expense and time for said compilation: "How can you do both?—the request is contradictory!" Given indefinite time and money, one can give an extremely accurate report. Reduction of either of these items will result in a corresponding change in the accuracy and scope of the air pollution emissions survey.

Even though a survey of this magnitude suffers from the usual compromise of time and money which prevents the development of specific data on source emissions and substitutes historical data, it is the first time that an air pollution control agency has been able to enter its control program with anything like adequate technical information. As just indicated, there are three bases for developing an air pollution control program:

1 Historical basis by which data from all other air pollution agencies having similar problems are evaluated according to degree of similarity, plus personal judgment.

2 Total knowledge basis which requires extensive development of information (i.e., surveys, etc.) concerning pollutant emission rates, location of pollutant sources, and related meteorological and climatological factors. Then, an understanding of the relationship between atmospheric concentrations of pollutants and their various effects will give an indication of the extent of pollutant regulation necessary to reduce the air pollution effects to limits acceptable by people affected.

3 Technological feasibility, which is a way of saying regulation limits are based on known capability of existing control equipment with some allowance made for economic factors.

Methodology

Early in March of 1958 a survey was initiated to obtain data as a basis for the writing of regulations limiting emission of solid and liquid particles from all sources, plus limiting of pollutant gases from combustion operations. It is the purpose of this paper to describe the procedures used in inventorying and evaluating these emissions in order to accomplish the District's objective. This paper was not written to show original work but rather to act as a guide and reference to others faced with similar problems.

The inventory can be broken down into four major processes:

1 Literature research.

2 Organization of a source survey questionnaire and evaluation of its results.

3 Use of stack sampling and atmospheric testing to provide additional data.

4 Application of experienced estimates by people and organizations well versed in the various fields of

* Presented at the 52nd Annual Meeting of APCA, June 22–26, 1959, Statler Hotel, Los Angeles, Calif.

source operation and familiar with the art of air pollution abatement.

Literature Survey

An engineer's approach to this inventory is to ask "How, when, where, and by whom has this operation been done before?", and "Can we find better methods of accomplishing the same result?" Naturally this leads to an immediate literature search. The literature search was facilitated by the use of the Bay Area Air Pollution Control District's microfilm library.[4] This library provides an extremely useful research tool to the District staff by offering over 7000 reference items on air pollution. The indexing and retrieval method allows quick location of reference items with almost unlimited expansion capacity. The literature search immediately showed extensive source survey work done by several State Health Departments,[5–8] research organizations, and commercial laboratories,[9–18] industry,[19–22] and many others.[23–46] Other libraries used are located at Stanford Research Institute in Menlo Park, Mechanics Institute, and the San Francisco Public Libraries in San Francisco, and the University of California Libraries at Berkeley. After digesting much of this data it became evident that in order to meet the limitations of time and money a source survey questionnaire would have to be designed to obtain the desired information.

Questionnaire

A rather novel method was used to plan this questionnaire. One of the staff's principal engineers prepared a first version of the questionnaire which was then criticized by the technical staff. The questionnaire was then sent for criticism to 2233 people in industry, health departments, and the Air Pollution Control Association. A cover letter explained the scope of the District and its need for an efficient questionnaire survey to supplement other information obtained by physical inspection and measurement of each source of pollution. There were 302, or 13.5% of the questionnaires returned, and of these 59 were satisfied, 30 wanted a simpler questionnaire, 88 were violent in their criticism, and 23 just returned the questionnaire either due to change of address or other reason.[47] Approximately 100 filled out the questionnaire in spite of a caption "sample copy for criticism only" written along the margin of each page. (And what is even more amazing is that some of the questionnaires filled out came from people 2000 miles away from our District's jurisdiction.) If this procedure is followed in the future it is recommended that the caption be written in one inch caps diagonally across the pages. However, this was a mixed blessing in that actually filling out the form by industry showed definite weaknesses in the questionnaire. Table I is a condensed tabulation showing active criticism to the questionnaire, including criticism assumed by omission of answering questions in the filled forms. Most of those who returned questionnaires believed that information was requested which most companies would be most reluctant, or unable, to answer (i.e., available reports on air pollution, plant maps showing location of vents, industrial classification, assessed valuation, annual production, and some meteorological questions). The critique by the health departments within the District and some members of the Air Pollution Control Association was characterized by a very definite criticism of the request for information on assessed valuation, annual production, plant maps, plus some concern with the complexity and wordiness of form. A few of the more noteworthy comments made were:

1 A questionnaire submitted to a large group should be as simple as possible, allowing for additional information on a follow-up basis.

2 The percentage return might be increased by use of a cover letter which explains that supplying the required data will result in a more intelligent air pollution control program.

3 Why should any company go to this degree of expense and co-operation when the information might be used as evidence against them?

The final questionnaire form shown as Appendix A was based upon a realistic analysis of the questionnaire critique. This form deleted some of the more objectionable questions and provided for security of information received. It was sent to approximately 1000 industries in the six Bay Area counties. This mailing list was a condensation of industry lists available from the Chambers of Commerce and county development associations. These lists contained a total of about 7000 operations, and the condensation to 1040 was accomplished by the District engineering staff. A cover letter explained the reason for the questionnaire, the purpose and scope of the District, and stressed the confidential status of the information so obtained. A copy of the law establishing the District was included with a letter reference to a certain section in this law which provides that "The control officer ... may require ... such information or analyses as will disclose ... the quantity ... of air contaminants ... discharged by such a source ..."

Table II summarizes the return on the questionnaire. Two hundred and fifty eight, or 25%, of the industries filled out the form and of that amount, only 20% gave really usable emission data. Some of these notable for quality of data are: non-ferrous, refinery, food, chemical, and cement industries. Although the questionnaire was initiated in March, critiqued by May, and sent on July 21, 1958, the 25% return did not occur until September 15, 1958. At this late date time for formulation of the District's regulations was short, and

Table I

Source Survey Questionnaire Critique: (Revised 3/30/59)

Individual Question Briefed	Number of Persons Against Use of Individual Question[a] — Industry	APCA	Health Dept.	Total
I. Form Disposition	2	0	—	2
II. A. Major products	0	1	—	1
B. Raw materials	5	4	—	9
C. Processes	6	5	—	11
D. Annual production	42	19	—	61
E. Number employees	2	12	—	14
F. Plant area	2	10	—	12
G. Assessed valuation	55	24	—	79
H. Operating schedule	1	2	—	3
I. Industrial classification	95	17	1	113
J. Plant maps show vents	96	17	—	113
K. Fuel consumption	33	3	—	36
III. A. Avail. reports on air poll.	96	18	2	116
B. Estimate your contaminants	94	17	2	113
C. Have air poll. program	25	3	2	30
D. $ spent on air poll.	35	4	—	39
E. Check air poll. control equip.	32	3	—	35
IV. A. Meteorological details	25	15	1	41
B. Meteorological records	24	14	1	39
Number Persons Satisfied with Questionnaire	29	28	2	59
Number Persons Suggesting Simpler Form	8	18	4	30

[a] Approximately one third returned the questionnaire merely filled out. Those questions which were left blank in this returned form were assumed to be criticized.

Table II—Percent Return of Industrial Questionnaires

Industry Category	Industrial Questionnaires Sent	Industrial Questionnaires Answered	Return, %
Steel	4	1	25
Ferrous	24	6	25
Nonferrous	50	11	22
Refinery and Allied	22	6	27
Chem. and Allied	176	37	21
Paint and Allied	63	16	25
Others	701	181	26
Grand Total	1040	258	Avg. 24.8

many gaps in emission data information remained to be filled either by stack sampling or experienced estimates.

Stack Sample Program

During August, as questionnaires were returned, it became apparent that many industrial sources of air contaminants had little or no knowledge of the quantities and characteristics of pollutants which they might be contributing to the atmosphere of the Bay Area. In many areas of interest no usable information was obtained from a search of the literature. Some of the areas of ignorance arose primarily because of the District's interest in the emission of small particles (5 microns diameter or less). The District's law requires that control regulations avoid specification of design of equipment or method of reducing emission of air contaminants. As a result the staff used questions covering the composition and characteristics of pollutants, which were perhaps somewhat more detailed than have usually been asked of industry in a survey of this nature, Published data of this type are scarce, and of questionable reliability. This is particularly true for the food industry, for some aspects of incinerator emissions, and for process heaters. Further, the staff felt a need for verification of some of the published data, such as that from the steel industry and petroleum refineries, even though such data were felt to be reliable.

The source testing group in the District, which were just beginning to function as an operating team, were asked to devote some of their initial efforts toward reducing these areas of ignorance. Since the design and procurement of testing equipment, the investigation and selection of various sampling methods, and the hiring of test personnel were still in progress during this period, the results obtained from these activities prior to the deadline for information submission were relatively few, and in some cases were of doubtful reliability. This is probably a situation which should be expected in most services of this nature, whenever the development of information as a basis for regulation and the development of the test program implementing such a regulation are carried on so nearly simultaneously, as is the case in a newly created agency.

Experienced Estimates

Because of limitations of time and staff, the bulk of the total emission survey data were the result of literature searches, industrial questionnaire survey, and estimates based on staff experience: some data were available from actual stack testing programs in the Bay Area (e.g., District's and Western Oil and Gas Association's surveys).

Early in the survey emission sources had been divided into combustion, metallurgical, and petro-chemical. A principal engineer was assigned to each source category and requested to estimate the total air pollution emission according to a form jointly agreed to in August. This form (see Table III) was developed so as to show as specifically as possible the chemical and physical nature of pollutants from given sources.

Combustion Sources consist principally of incineration, transportation, natural gas, and fuel oil burning, and agricultural burning.

Incineration is divided into three general categories: (*a*) residential, (*b*) commercial, and (*c*) wood and sawdust burners.

"Residential" includes the use of backyard incinerators and some backyard open burning. Data in the technical literature[48, 49] indicate that four pounds of waste material are generated per capita per day; after deducting the material hauled to land fills it was estimated that 1.25 pounds per capita per day are burned in backyards. For a population in the Bay Area of three million this results in 1875 tons per day burned. The quantities of various emissions from residential burning was taken from a research study at Battelle Memorial Institute on effluents from backyard incinerators.[50]

The calculated quantity of material burned in commercial incinerators was based on the same two survey sources as for residential burning.[48, 49] The University of California calculated that 1.4 pound per capita per day was burned in commercial incinerators and a report by the Air Pollution Foundation[51] showed that one pound per capita per day was burned. Therefore, a conservative figure of one pound per capita per day was used. Emission quantities from commercial incinerators were based on the work of Battelle on backyard incinerators.[50]

The quantity of wood waste products burned was based on the Stanford Research Institute Portland Survey[48] which used Los Angeles data of two pounds per capita—resulting in 3000 tons per day for the Bay Area. The emission quantities from wood burners were based upon results in this same report.

Emissions from gasoline powered vehicles were based on the total vehicle registration in the District (1,279,000) and a gasoline consumption of 800 gal per year per vehicle. The number of diesel trucks and buses was estimated from a breakdown on type of engines in trucks supplied by the California Trucker's Association, which was applied as a percentage to the registration in the Bay Area. Railroad locomotive fuel consumption was supplied by the railroad companies. Emission quantities for gasoline-powered vehicles were calculated from Los Angeles data.[52] The Stanford Research Institute Portland Survey[48] was used for diesel vehicles.

Natural gas consumption was based on the maximum month's consumption in 1957 reported by Pacific Gas and Electric Co. It is to be noted that this includes gas used for power generation. The emission quantities used were based on the latest data supplied by Stanford Research Institute.[53]

The quantity of material burned in agricultural operations was supplied by the University of California Extension Service. A breakdown of the quantity burned each month during crop waste burning season was made; the quantity was reported as being representative of the majority of the days during this Fall period. Emission quantities were calculated from data on backyard incinerators[50] because of the similarity of materials burned and the nature of incomplete combustion that occurs in both instances. These emissions have been verified in part by field and laboratory measurement work of the District.

The quantity of fuel oil burned was based on Western Oil and Gas Association estimates made in 1956, and emission quantities were taken from data by Stanford Research Institute.[53]

Metallurgical Sources consist of metal and mineral industries sources. The work which has been done and publicly

reported in the field of measuring and controlling emissions from metallurgical and mineral processes is substantial. Air pollution problems from this type of process have long been recognized and most of the present day universally accepted engineering controls were developed by these industries.

As a result of this work a considerable volume of data has appeared in the literature which is pertinent to the present survey and has been confirmed and widely accepted.[54–61] By this means it was possible to develop figures for most of these operations which relate weight of air pollution emission to total production. The figures shown in Table III within this category were calculated from these data applying production figures for the actual operations within the District.

At present the open hearth steel operations are the largest sources of uncontrolled particulate emissions within this category. In addition, their emissions are known with a greater degree of assurance than for any other source within the metal and mineral industry.

Iron and steel foundries include both cupola and electric furnace operations. Here again, much work has been done and emission data from these sources can be stated with a fair degree of assurance in spite of varying emission rates depending upon local technique.

While each nonferrous foundry contributes relatively small tonnages of total particulates, the total emission results from a large number of small operations.

The category "kilns and dryers" includes such operations as cement making and lime calcining, all of which are inherently dusty processes because the end product is dust. Considerable data have been accumulated on emissions from cement plants and lesser amounts on the other operations within this classification. For Bay Area cement plants data from published literature were interpolated, based on capacities and degree of control known for these plants. For the other operations a "best estimate" had to be used based on general knowledge of the kinds of operations and their relative sizes.

The "ceramic" classification includes the manufacture of tile, brick, refractories, and glass. Data for glass plants are plentiful, but the air pollution emissions from remaining members of this group are not well known. In these cases the estimates made were based on general knowledge of the operations. The last group within this category contains a wide range of operations. The most important air pollution contributors in this group were judged to be asphalt mix plants, concrete batching operations, sand and gravel quarrying and handling, and miscellaneous grinding operations. Little data were available and only estimates could be made.

Petro-chemical Sources include refineries, chemical plants, and the food industry. The air pollution emission data from refineries in the District are considered firm since detailed emission surveys were carried out by each of these four refineries (the reports of which were made available to the District). Additional literature references were used, however, for checking refinery emission data and for calculating emissions from the other operations in this category.[62–73]

Other than from refineries the emissions from this group of operations were calculated largely from data developed by Stanford Research Institute.[59] The estimates in this report are based on known energy requirements and air pollution emissions for particular operations. In this way, knowing the total energy consumption of a given group of operations in the Bay Area it is possible to calculate their estimated air pollution emissions.

Conclusions

The total emissions survey provided a comprehensive inventory of the amounts and types of pollutants emitted. These data furnished a basis for the development of regulations in the Bay Area.

All air pollution engineers would agree that the ideal way of determining total air pollution emissions within a given area would be to sample every source or at least single representatives of each category of sources. However, time and money never seem to permit this approach. Regardless of how frustrating some of the necessary compromises might at first appear to the technical man, a valuable survey can be made even in a complex situation that can form the basis of sound decisions

Table III—Estimates of Air Pollution Emissions (Tons per Day)

Source of Emission	—Particulates (Dusts-Droplets)[d] Size Ranges in Microns 0–5	5–20	20+	Total Particulates	Gases—Organics—Hydrocarbons Sat.	Unsat.	Other Organics Aldehydes and Ketones	Alcohols, Esters, etc.	Total, All Organics	—Inorganics— Nitrogen Oxides	Sulfur Oxides
Combustion											
1. Incinerators[c]	27	9	37	73	169	128	74	82	453	3	3
2. Fuel Oil[c]	6	←——→	6	12	1	—	1	2	4	86	177
3. Fuel Gas[a]	3	—	—	3	1	—	1	18	20	80	2
Subtotal	36	9	43	88	171	128	76	102	477	169	182
Metallurgical											
1. Steel[c]	19	2	1	22	—	—	—	—	—	—	2
2. Ferrous[a]	3	2	7	12	←———				—1	—	1
3. Nonferrous[b]	3	1	1	5	—	—	—	—	—	—	97
4. Kilns, Driers, Ceramic[b]	4	2	5	11	—	—	—	—	—	—	2
5. Other[c]	4	3	7	14	13	3	←——→	3	19	—	2
Subtotal	33	10	21	64	14	3	←——→	3	20	—	104
Petrochemical											
1. Refinery and Allied[a,b]	12	←——→	11	23[a]	90	8	2	—	100[b]	35[a]	150[a]
2. Chem. and Allied[c]	5	←——→	58	63	51	7	←——→	28	86	8	68
3. Food and Kindred[c]	1	←——→	2	3	10	—	←——→	2	12	10	5
4. Paint and Allied[c]	1	←——→	1	2	78	12	←——→	34	124	2	11
Subtotal	—	—	—	—	—	—	—	—	—	—	—
Subtotal	19		72	91	229	27	2	64	322	55	234
Total	88	19	136	243	414	158	78	169	819	224	520
Other											
1. Transportation:											
a. Gasoline[b]	16	—	—	16	431	101	7	8	547	222	24
b. Diesel[c]	10	6	—	16	35	12	2	5	54	15	6
2. Agricultural Burning[e,c]	25	10	25	60	375	350	180	95	1000	2	4
Subtotal	51	16	25	92	841	463	189	108	1601	239	34
Grand Total	139	35	161	335	1255	621	267	277	2420	463	554

[a] Firm date. [b] Fair data. [c] Estimate. [d] Only tonnage figures reflect firmness of data (*a*, *b*, and *c*)—particle size is based on meager data and judgment factors (exception is metallurgical data based upon accepted published data). [e] Based on the month of peak seasonal burning—October.

for a total air pollution control program.

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Appendix A
—Total Emissions Survey: Industrial and Commercial Sources

Company name_____
Address_____
Name and Title of Person to be contacted on air pollution matters:
_____Phone No._____

Note: The balance of this questionnaire will be held in confidence.

I. What disposition shall we make of this form after statistical treatment? Destroy _____; Retain in our District files_____; Return to Industry_____.

II. General Plant Information

A. What are your products or services? (Indicate quantity produced/yr)_____

B. What are your raw materials (Indicate quantity consumed/yr)_____

C. What is the approximate average number of employees?
1–8_____, 9–19_____, 20–49_____, 50–99_____, 100–249_____, 250–499_____, 500–749_____, 750–999_____, 1000–over_____,

D. What is your normal operating schedule? Hr./day____, days/week____, months/year____. Describe any major seasonal variation_____

E. Please tabulate fuel and energy consumption, as indicated below:

Type	Fuel and Energy Consumption — Space Heating	Power Generation	Processing	Wt or Vol % of Sulfur
Natural Gas	Ft^3	Ft^3	Ft^3	XXX
	Mo	Mo	Mo	
Process Gas[a]	Ft^3	Ft^3	Ft^3	
	Mo	Mo	Mo	
Fuel Oil	Bbl.[b]	Bbl.[b]	Bbl.[b]	
	Mo	Mo	Mo	
Electricity	Kwhr	Kwhr	Kwhr	XXX
	Mo	Mo	Mo	
Other (Coke,[a] etc.)	Ton	Ton	Ton	
	Mo	Mo	Mo	

[a] Specify type and/or source. [b] 1 barrel equals 42 gallons.

III. Air Pollution Information (Please describe any checked items on attached sheets).

A. Please check any of the following items that you have:
_____1. Any regular air pollution emission measurement program? By plant personnel _____, By contract_____.
_____2. Any stacks equipped with sampling ports, ladders, platforms, etc?
_____3. Air pollution control equipment serving any stacks?

B. What is the approximate quantity of your combustible waste material? Tons/year —— or yd^3/year_____. Approximately what percent of above is incinerated on the premises _____%.

C. Approximately what dollar amounts have you spent on air pollution control equipment prior to Dec. 31, 1955? _____, in 1956?_____, in 1957 _____, in 1958 to date? _____, planned future _____? What percent of building and equipment investment is represented in air pollution control equipment? _____.

D. Do you have a program of maintenance and efficiency checks on your air pollution control equipment? Yes_____; No_____.

E. Please describe material emitted to the atmosphere and any control equipment used for each process or operation as indicated in the tabulation below. If you have more information that can be entered in the table, please use additional pages and attach to form.

Process or Operation Causing Emission[a]	Material Emitted Into the Atmosphere: Dust[b]	Droplet[c]	Gas[d]	Weight % or Volume %	Tons per Year	Collector or Other Control Equipment: Type	Rated Capacity	Cleaning Efficiency, %	Date Installed

[a] Such as boiler or furnace, conveyors, incinerators, tanks, ovens and dryers, spray booth, and coating system, etc.
[b] Fly ash, cement, catalyst, metal oxides, etc.
[c] Acid, bases, hydrocarbons—oil, tar, etc.
[d] Hydrocarbons, nitrogen oxides, sulfur oxides, aldehydes, ammonia, etc. (exclude water vapor, nitrogen, carbon dioxide, and oxygen).

F. Do you have any air pollution emission reports available for use by our District on a confidential basis? Yes———; No———.

G. Please check any of the following measurements of weather at your plant which you record:

1. Wind Speed———— 4. Humidity————
2. Direction———— 5. Rainfall————
3. Temperature———— 6. Other———— (evaporation, etc.)

H. Are you using odor control additives? Yes ———; No ———.

I. Are there any present commitments for changes in production, quantities or processes, waste recovery, or other factors reported above that might affect any of the information? Yes———; No———; What ————.

IV. Additional Remarks

Please use extra sheets as needed for completion of answers or for any additional comments. Identify answers by question numbers, as II-E, III-A, etc.

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Welcome New Members

Galer, Richard E.
Alpena, Michigan

Gill, Gerald C.
Ann Arbor, Michigan

Gran, Gunnar
Stockholm, Sweden

Greenberg, Abraham
New York, New York

Gustavson, F. R.
Mountain View, California

Hall, W. C.
College Station, Texas

Harvey, Gordon B.
Rochester, New York

Hauser, R. E.
Cincinnati, Ohio

Herrington, Kenneth Ray
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Ingen, Richard Van
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Toronto, Ontario, Canada

(Continued on page 340)

ATMOSPHERIC POLLUTION PROBLEMS *of the* PUBLIC UTILITY INDUSTRY

Informative Report No. 1

Committee TI-5, Public Utilities, Thermal Electric Plants

Sources of Potential Air Pollutants

The air pollution problems of the public utility industry are almost entirely those arising from the release of the products of combustion and from the storage and handling of fuels.

Steam-electric generating stations are the principal public utility users of fuel and therefore are most concerned with air pollution. In such stations the heat from fuels burned in boiler furnaces produces steam. The thermal energy in the steam is converted to mechanical energy in turbines and in turn to electrical energy in generators driven by the turbines. Only minor amounts of fuel are used in the manufacture of artificial gas, by natural gas transmission and distribution systems and by water supply systems.

Fuels

The fuels commonly used in the thermal generation of electricity in the United States are those commercial fuels which are available in sufficient and economical supply; namely, coal, natural gas, and residual fuel oils. In the year 1958, which is representative, approximately 78% of the electrical energy for the United States was generated at fuel burning stations and of this thermally produced energy, 68% was produced with coal as fuel, 24% with natural gas, and 8% with fuel oil. Also in 1958 the steam-electric generating stations used approximately 155,708,000 tons of coal, 1,372,881 million cu ft of natural gas, and 77,650,000 barrels of fuel oil. This means that about 30% of the coal, 13% of the natural gas, and 15% of the fuel oil used in the United States in 1958 was burned in electrical generating stations. Comparatively minor amounts of industrial gases, coke, and industrial wastes are used as fuels in utility stations. In the United States in 1958, the average generating station used approximately 11,000 Btu of thermal energy for each kilowatt hour produced.

Air Pollutants

The products of combustion which are most commonly released by steam-electric generating stations included (*1*) solid materials, such as unburned carbon particles and incombustible ash particles of various types and sizes and (*2*) gases which include (*a*) carbon dioxide, (*b*) carbon monoxide, (*c*) water vapor, (*d*) sulfur dioxide, (*e*) sulfur trioxide, and (*f*) nitrogen oxide. The storage and handling of fuels may cause the release of dusts, small particles and vapors.

1 All of the solid materials which are emitted from combustion processes are generally considered air pollutants. Steam-electric generating stations normally emit little if any smoke in the sense of unburned carbon particles. Combustion is as nearly complete as is practically possible and an excess of combustion air is always provided. Ash particles caused by incombustible materials in the fuels appear in stack discharges in various forms, depending on the fuels and the methods of burning. The most common forms include comparatively small particles from coal fuel which are usually referred to as fly ash, larger coal ash particles which are commonly called cinders and particulate materials from oil fuel fires.

2 Among the common gases released by the combustion processes are:

(*a*) Carbon dioxide which is caused by complete combustion of carbon in the fuel. This gas is normally not considered an air pollutant.

(*b*) Carbon monoxide which is formed by incomplete combustion of carbon in the fuel. This gas is considered an air pollutant but is seldom found in significant quantities in power station stack discharges, as effective combustion control devices and an excess of combustion air are provided in order to assure complete combustion.

(*c*) Water vapor which is formed by combustion of hydrogen in the fuel and may in addition be drawn in with combustion air. Water vapor is usually not considered an air pollutant.

(*d*) Sulfur dioxide and (*e*) sulfur trioxide which are formed by combustion of sulfur. Sulfur is present as an impurity in many industrial fuels. Both of these gases are considered air pollutants. The concentrations of sulfur dioxide in stack effluents from power stations will usually be about 600 ppm by volume for each 1% of sulfur by weight in the fuel. The concentrations of sulfur trioxide will usually be about 1 to 2% of the sulfur dioxide concentrations.

(*f*) Nitrogen oxides, which are released by all common types of combustion, are formed by the oxidation of atmospheric nitrogen at high temperatures. Nitrogen oxides have not been considered important general atmospheric pollutants by themselves, but it now appears that they react photochemically with hydrocarbons which may be present in the atmosphere and which by themselves are also comparatively innocuous, to form important air pollutant compounds, such as are found in the Los Angeles type smog. Nitrogen oxides, principally in the

form of nitric oxide, occur in steam-electric station stack discharges in concentrations of from less than 100 ppm to more than 1500 ppm. These concentrations, which are affected critically by maximum temperatures and rate of cooling of the combustion gases, vary with load, fuels, furnace design, and combustion conditions.

It should be noted that these previously mentioned air pollutants are released from power station stacks in concentrations which are much lower than are found commonly in the discharges from many industrial processes.

The air pollution problems associated with the storage and handling of fuels are principally those concerned with dusts and particles released from coal storage and processing areas and the vapors emitted from fuel oil storage tanks.

Coal Burning Stations

Steam-electric generating stations using coal for fuel usually release the generally recognized air pollutants of fly ash (and/or cinders), sulfur gases and nitrogen oxides in the furnace effluents.

Coal in crushed or pulverized form is suspended in combustion air and is fed into the furnace in this manner in most of the larger and more modern furnaces. Combustion takes place in fuel beds or on grates only in comparatively small or older furnaces. In some types of coal burning furnaces, a considerable amount of the incombustible ash remains as furnace slag with a corresponding reduction in the amount of fly ash or cinders which is released in the furnace gas streams.

Coals of commercial grade which are obtainable in sufficient supply for utility use normally contain from 5 to 15% of incombustible ash. This incombustible material must either be removed as furnace slag, removed from the furnace gas streams with collectors or released from the boiler stacks. Combinations of mechanical collectors for larger particles and electrostatic precipitators for the finer materials have been developed which can remove as much as 99% of the ash particles under favorable conditions. The disposal of the large quantities of ash collected by such devices presents many practical problems.

Sulfur appears in commercial grade coals in amounts varying from less than $^1/_2$% to more than 5% by weight. The combustion of this sulfur produces the sulfur dioxide and sulfur trioxide gases which are among the most common air pollutants in general. A small part of the sulfur may appear as sulfation of metallic elements in the ash and of furnace surfaces. Although many efforts have been made and are continuing, no practicable method of removing sulfur from coal or of removing sulfur gases from generating station stack effluents has been developed. The industry is diligently pursuing the problem by promoting and supporting research directed towards reducing or eliminating sulfur from the fuel source and/or from the combustion products. Methods which have been effective in removing sulfur gases from industrial process gas streams are not practicable on the large volume gas streams containing comparatively low concentrations of sulfur gases which are released from utility stations.

Nitrogen oxide is discharged from coal burning steam-electric station boilers in concentrations from about 100 ppm to more than 1400 ppm. These concentrations vary with load, furnace design, combustion conditions, and to some extent with the fuel. No practicable method of removing nitrogen oxide from utility station stack gases is presently available.

Coal burning stations usually produce visible plumes which are believed to be caused by ash particles, a small amount of sulfur trioxide aerosol and water vapor in the stack gases. The installation of precipitators will materially reduce plume formation by removing a high precentage of fly ash but does not completely eliminate the plume.

Sprays and coatings are available which may be used to reduce the emission of coal dusts from storage and handling areas.

Natural Gas Burning Stations

Furnaces using natural gas for fuel normally discharge little or no particulate matter, sulfur gases in proportion to the amount of sulfur in the fuel, which is usually insignificant, and nitrogen oxides.

Comparatively simple burners are usually provided to introduce the gas fuel into the furnace and to assure intimate mixing with the combustion air.

Nitrogen oxide concentrations in the discharges from natural gas-fired utility boilers vary from less than 100 ppm to more than 1300 ppm depending on load, furnace design, combustion conditions, and fuel. In boilers which are equipped to burn several different fuels, natural gas will usually produce somewhat lower concentrations of nitrogen oxides than either coal or fuel oil. Practicable methods for removing nitrogen oxide from stack discharges have not been developed.

Natural gas fires usually produce no, or only faintly visible plumes, but under some meteorological conditions, the water formed by combustion may form a conspicuous vapor plume.

Furnace, coke oven, refinery and other industrial by-product gases, which are sometimes used in utility furnaces, often contain impurities which result in the discharge of pollutants which are not common in the effluents from stations burning natural gas. Although these industrial gases are a minor fuel source, their resulting pollutants may cause local problems.

Fuel Oil Burning Stations

Utility stations using fuel oils usually release ash particles, sulfur gases, and nitrogen oxides as air pollutants from the stacks.

Fuel oils are usually atomized and discharged into the furnaces closely mixed with heated combustion air. Means for heating the oil before it is atomized are usually provided in order to control viscosity and insure adequate atomization.

Most fuel oils contain less than 0.2% incombustible ash, which appears in the stack discharges as particles which commonly vary from submicron to 40 microns in size. The amount of such particulate material from an oil fired boiler is usually only roughly 1 to 2% of that released from a comparable boiler burning coal. Mechanical collectors may be used to collect the larger particles and electrostatic precipitators or filtering materials will remove the finer particles from oil fired boilers, but because of the comparatively small quantities of material which are involved, the complications and expenses of providing particle removal equipment for utility station boilers using fuel oil are seldom justified.

The sulfur content of commercial fuel oils varies from less than $^1/_2$% to more than 4% by weight. As with coal fuel, many efforts have been made to develop practicable methods for removing the sulfur from the fuel or of removing the sulfur gases from the stack gases, but without success to date.

Nitrogen oxide concentrations in the stack effluents from fuel oil burning stations are from less than 100 ppm to more than 900 ppm, depending on load, furnace design, combustion conditions, and the oil. In general, for comparable conditions, it appears that fuel oils produce somewhat higher concentrations of nitrogen oxide than does natural gas, but lower values than does coal. Practicable methods for removing nitrogen oxides from stack gases are not available.

Plumes from oil burning stations are apparently due to the particulate matter, which in the smaller particle size range has a disproportionate plume forming effect per unit of weight, to the small amount of sulfur trioxide aerosol usually present and to water vapor.

Release of vapors from fuel oil storage tanks may be minimized by sealing of tank roofs and providing vapor traps for the vents, but this is

seldom necessary.

General

The public utilities have a primary responsibility of providing reliable, economical power in continually increasing amounts to meet the demands of their customers. Such service must be provided in order to protect the health, safety, and welfare of the public. In meeting this primary responsibility, the utilities must consider many factors in addition to that of minimizing air pollution.

The fuels which may be used at utility stations cannot be chosen on the basis of air pollution characteristics alone, but the selection must also depend on the availability and reliability of an adequate supply and in many cases on the policies of governmental regulatory agencies. All public utilities are regulated in one manner or another as to the rates which may be charged and in addition, there is competition from other types of energy and from individual generating sources. These economic factors limit the ability of the utilities to pay premium prices for fuels, as even the costs of the most economical fuels constitute major parts of the operating costs of utilities which rely on steam-electric generating stations.

Air pollution considerations alone cannot be used by public utilities in selecting locations for steam-electric generating stations. An acceptable site for such a station must provide the usual space, foundation and transportation requisites of any industrial tract but also must have an adequate supply of water, both for condenser cooling and for boiler makeup, provisions for a firm source of fuel including storage areas for solid or liquid fuels and satisfactory electrical transmission facilities for delivering the power to load areas. As examples of the magnitude of these problems, for every 100,000 kw of capacity in full production, a steam-electric station will require each day roughly 60,000,000 gallons of cooling water and 1000 tons of coal or 25,000,000 cu ft of natural gas or 170,000 gallons of oil for fuel. Rights-of-way for electrical transmission lines are difficult to obtain, each additional mile of such line which is required decreases the reliability of the power source by adding exposure to hazards which can cause interruptions to the flow of power through the line, electrical losses increase with line length and the costs of transmission lines with their rights-of-way in metropolitan areas may be as much as several hundred thousand dollars per mile.

Committee Members

A. C. Pasini, Chairman, H. C. Austin, G. W. Bice, C. S. Bilisoly, F. J. Leonhard, E. H. Man, D. F. Schick, L. A. Winkelman, O. D. Whiddon, Secretary.

Advisors: W. C. Beattie, A. A. Casey, G. V. Williamson.

Prepared by—H. C. AUSTIN

Informative Report No. 2

Control of Air Pollution and Practical Limits of Emission

Introduction

What degree of air pollution control is justified? This question represents one of the most important air pollution problems facing government and industry. There is no single answer to the question; however, certain guiding principles have been evolved which have an important bearing on the problem. This report presents these principles as they are understood in the electric utility industry.

Fundamentally the control of air pollution is necessary to some reasonable degree. The electric utilities have acted on this premise to help develop practical control equipment. They have installed control equipment, usually far exceeding legal requirements. A look at the stack of a modern thermal electric plant reveals the good results. One sees only a light colored plume containing no smoke and only a small amount of fly ash.

With few exceptions, air pollution control is an expense to industry. For instance, the collection of fly ash gives very little economic return. Possibly, future developments will improve this situation. At least for the present, there is the adverse effects of air pollution as well as the cost of controlling air pollution which eventually must be paid for by the public.

Both government and industry must work together towards a realistic and reasonable air pollution control program which will minimize total costs to the public and best serve the public interest.

Industry can contribute to this effort; government control officials can promote a co-operative attitude by exhibiting a willingness to accept worth-while industry suggestions. Lack of co-operation will result in unrealistic and impractical controls being imposed upon industry, with a resulting high cost to the public and lack of progress in the science of air pollution control.

The electric utilities have a very real interest in air pollution, both from an economic standpoint and as a good citizen of the community. The reason for this interest is to maintain a healthy business climate and to serve its customers—the public.

Principles of Control

Certain specific principles are recommended for guidance in establishing or modifying air pollution control programs affecting public utility thermal electric plants:

1. Establish a program which is based on a common objective for government and industry to provide the greatest over all benefit to the public.
2. Recognize the need for individual treatment for each area and each problem.
3. Use practical performance standards based on the minimum total costs to the public.
4. Recognize the need for education of the public, as differentiated from propaganda, both by government and industry.
5. Provide for deletion of controls and requirements that are of little or no value.
6. Recognize the difference in cost that usually exists when equipment is included in new installations and rebuilding old installations.
7. Recognize the importance of furnishing low cost electric power to the public as a part of the everyday well being when determining the extent of action to secure air pollution control.
8. Allow for flexibility in the solution of air pollution problems to promote research and participation of industry in finding better and less costly methods of control.
9. Set up a program so that engineering advances, improved knowledge of air pollution effects, and any other advances can be utilized to improve the control program.
10. The establishment of new standards may cause extreme hardship to existing plants unless a reasonable time is granted for complying with the new standards. Each hardship caused to existing plants should be treated individually. Relief should be granted, based on the extent of air pollution from the individual

plant, the cost of correcting the variance and the engineering feasibility of making the correction.

Performance Standards

The three factors which should be used to determine the difference between unwarranted air pollution and normal use of the atmosphere for disposal of waste products are:

1 Creation of a health hazard.
2 Damage to property.
3 Creation of a nuisance.

In the absence of any of the foregoing factors, either actual or potential, there would be no cause for setting up a performance standard. If these factors are present, the degree to which they exist should be the basis for establishing the level of performance standards. The performance standard normally should not be given as a single number to cover all situations such as a dust collector efficiency value, but should recognize that many circumstances affect any one or all of the three air pollution factors. Such things as topography, stack height, prevailing wind direction, and velocity, weather conditions, anticipated plant load conditions, size analysis of solids emitted, and gas exit velocities may collectively or individually have more affect on air pollution as judged by dust dispersion than collector efficiency. The individual and combined effects of the various factors will also vary with each problem. Therefore, it does not appear feasible to recommend a universal set of practical limits of emission based on specific performance standards, nor to recommend a universal solution to the problem of bringing discharge of pollution under control.

Under certain circumstances, the most advanced and costly equipment available may not be adequate to control air pollution properly. Other situations may justify only a very casual treatment. Certainly, a realistic control program will recognize this inherent difference with a resulting benefit to all concerned.

The foregoing statements lead to the following recommendation as a general criterion for establishing limits of emission for the thermal electric plants of public utilities:

> The emission of pollutants to the atmosphere shall not exceed any value which will cause a nuisance, health hazard, or property damage to the public which deprives the public of any of its Constitutional rights, or causes a loss to the public which is greater than the cost of reducing or eliminating the emission of the pollutants.

The effectiveness with which the limits of emission can be enforced will depend primarily on four factors: the legal provisions that are established, the degree of co-operation that is established between government and industry, the technical skill of the enforcement group, and the adequacy of equipment available to the enforcement group for measuring the degree of air pollution. To be practical, the establishment of a violation must not be the function of a person or group of people lacking technical competence. Safe-guards should be included in any ordinance to insure that enforcement is based on a recognition of the problem of air pollution for what it is—a highly specialized technical problem. Any shortcomings in the area of enforcement—arbitrary or unreasonably strict requirements, or the permission of flagrant violations—can result in failure of an air pollution program.

The following list of potential pollutants which could be emitted from thermal electric plants is for general information. More detailed information is available in other literature prepared by TI-5 and from other sources.

Emitted Material	Comments
Gases from burning of fossil fuels	Contains primarily carbon dioxide, nitrogen, oxygen, and water vapor; also, small quantities of sulphur compounds in gaseous state, chloride compounds, carbon monoxide, nitrogen oxides, and other trace amounts of gases. Primary means of control is by dispersion and limiting location of plant by reasonable zoning where zoning restrictions are practical.
Fly ash	Primarily noncombustible ash from coal burning, usually contains a small amount of unburned carbon. Primary means of control is by removal from combustion gases by collectors, dispersion and limiting location of plant by reasonable zoning where zoning restrictions are practical.
Smoke	Primarily unburned carbon (carbon black) as fine particles which are gas borne. Primary means of control is by maintaining good combustion conditions, using proper fuel for the design of furnace, efficient operating methods, and dispersion. Location of plant by zoning control also helps prevent development of an air pollution problem.
Coal, dust, fumes, odor, and other pollutants	These pollutants are normally of a secondary nature, but where they are of importance, usually adequate means can be found for control.

A major problem in connection with the control of emission from a modern thermal electric plant is the size of the operation. Any treatment of stack gases involves tremendous expenditures, even the installation of a simple dust collector for instance. Therefore, the application of a successful pilot plant operation to full scale operation may be delayed more by the economic considerations than by the technical problems, and with good reason.

In summary, a great deal of effort in excess of the demands by government regulations has been devoted to air pollution problems by public utilities operating thermal electric plants. This attitude should be encouraged. Enforcement officials can promote this positive approach by exhibiting a willingness to work with industry towards further developing the air pollution control programs and by recognizing individual problems as well as the over-all cost balance picture in determining standards of performance. Such an approach demands that highly trained personnel be utilized for writing air pollution control ordinances and for administering these ordinances. The present state of knowledge and methods of control do not permit oversimplification; however, with proper handling, the air pollution from thermal electric plants can and should be adequately controlled.

Finally, the public must be informed that air pollution control is achieved at a price. The cost, either directly or indirectly, is borne by the public. Therefore, the people of a community must first decide how much they are willing to pay for air pollution control, and then see that adequate laws are passed and qualified personnel are made available to work with industry to achieve the desired air pollution control.

Prepared by—O. D. WHIDDON

LEAD *and* ARSENIC *Report*

Informative Report No. 1

Technical Co-ordinating Committee TI-8, D. J. BLYTHE, Editor

This is a brief report on the methods and techniques that are employed in controlling metallurgical fumes produced during the smelting, refining, and alloying of secondary lead and its alloys.

In view of the toxic properties of lead and its alloying constituents, particularly arsenic, most of the secondary lead plants in the United States have adopted various methods to eliminate these elements from their stack emissions. The adoption of these methods, in many cases, has resulted in a substantial savings to the metallurgical economics of their respective operations along with suitable air pollution control.

The extent of the air pollution control methods used by the secondary lead industry is basically a function of type of metal operations being conducted in the individual plants with regard to the requirements as stipulated by local and state air pollution ordinances. In some areas the allowable emission discharge permitted by air pollution statutes are extremely low, such as 0.00006 grains per cu ft for lead, while in other areas the tolerances are considerably higher. Consequently, there is a variation in the methods and techniques for preventing air pollution that are used by secondary lead plants throughout the country.

In general, plants which are engaged in secondary lead smelting with either a blast furnace or a reverberatory furnace require an extensive system of air pollution control. The reason for this is that secondary smelting usually entails the treatment of scrap lead storage batteries and lead residues which, on smelting, generate a heavy metallic laden fume that has an unpleasant odor. The principal components contained in this type of fume, as related to blast furnace operations, are metallic oxides of lead and its alloys, organic matter, sulfur dioxide, tar volatiles from battery cases, and various carbon-oxygen-sulfur compounds. The fumes from reverberatory smelting furnaces are similar in composition but usually have a lower content of tar volatiles and organic matter.

In order to condition the fumes arising from secondary smelting operations for emission into the atmosphere, it is necessary that the fumes undergo a series of filtering and cleaning processes. At present the processes which have found the greatest acceptance are those that filter the fume through cloth bags and have a collecting efficiency of well over 99% of the solids. About one square foot of bag area is required for each cubic foot per minute of gas filtered. Other methods which are used in some plants, include passing the dust laden fume through either a series of settling chambers or water spray curtains before releasing the fumes. These methods are not generally as efficient as cloth filtering because they remove only the coarser particules, allowing smoke and metallic fumes to be discharged into the exhaust stacks.

The secondary lead smelters which are located in areas where air pollution control is very strict usually treat the emissions from their smelting furnaces in the following manner. The hot emissions from the smelting furnaces are first cooled by passing them through a series of cooling tubes that are being water or air cooled. The emissions, after leaving the cooling units at a temperature around 250°F are then sent into a baghouse which contains woolen or synthetic fiber bags. In the baghouse the dust and fume particles are filtered out. The collected material which is shaken mechanically from the filter bags into the cellars below the bags is normally sintered to facilitate its subsequent recharging into the smelting furnaces. The temperature of the baghouse must be kept fairly high to prevent the tar volatiles from condensing and blinding the bags. Lime is added to the emissions as it enters the baghouse to help prevent this blinding action. The metallic assay of the dust collected in the baghouse is often well over 50% by weight. On leaving the baghouse the gas stream may then pass directly into the stack for discharge or it is in some instances further treated in an electrostatic precipitator in order to meet the ordinance requirements.

It should be noted that in the procedure just described small amounts of sulfur dioxide and the unpleasant odors of the carbon-oxygen sulfur compounds are discharged along with the final effluents to the atmosphere. To prevent this condition a few plants have installed equipment which will eliminate the odor and effect a combination of most of the sulfur dioxide with the fume. From a metallurgical viewpoint the addition of sulfur to the fume is not too desirable but the odor and sulfur dioxide discharged from the exhaust stacks are almost completely eliminated by the operation.

In the refining and alloying of secondary lead the air pollution problems are not as complex as those arising from the smelting of lead scrap. This is mainly due to the fact that most of the refining and alloying are done at comparatively low temperatures in hooded steel kettles below the volatilization point of the metals being treated. The reagents used in the refining operations for secondary lead and its alloys very rarely produce corrosive gases or objectionable odors that would cause air pollution problems. Thus, the fumes produced from the refining and alloying can be effectively treated by collecting them from the kettle hoods with a flow of around 200 cfm and passing them through a baghouse for filtering. The baghouses used for this purpose may operate with cotton bags. The dust collected from the fume in the baghouse can be stored in hoppers to await further treatment to recover the metallic values. In some locations secondary lead plants do not filter the fume from their refining and alloying

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Air POLLUTIONAL ASPECTS *of* WASTE DISPOSAL

PART I—Land Burial, PART II—Salvage

Informative Report No. 1

Committee TA-2, Waste Disposal

The first two major sections on the "Air Pollutional Aspects of Waste Disposal," as prepared by Committee TA-2 Waste Disposal, is published herewith.

Since additional sections are to be covered, the report is partial; however, the report herewith submitted has been reviewed and commented upon by the Technical Council and amendments concurred in by the Waste Disposal Committee TA-2.

It is intended that the first two sections be followed by Part III which will relate the practice of incineration to the matter of air pollution control.

In general, air pollution results largely from man's activities and is accentuated by his gregarious habits which cause concentrations of activities. Problems of waste disposal are compounded by these same factors, resulting in an interrelation between waste disposal and air pollution. The Waste Disposal Committee has been charged with the responsibility to examine waste disposal procedures and to ferret out those practices which contribute to air pollution, while recommending for usage those practices which seem to be relatively free from air pollution. The conclusions in this report have been derived from an exchange among engineers, scientists, technicians, and manufacturer's representatives from differing geographical regions and are felt to embody the current thinking of most of those presently engaged in practices of waste disposal.

Part I—Waste Disposal by Land Burial

Open Dumping

The dumping of crude municipal refuse or putrescible industrial wastes upon the surface of the earth or in open pits without frequent and carefully controlled covering is not considered satisfactory from public health, esthetic, engineering, and air pollution considerations. Decaying of decomposable materials and exposure of odorous wastes will release objectionable air pollutants which can both create nuisances within immediate environs and add materially to the air pollutional load of the atmosphere. Dust from piles, dumping operations, and flying debris during windy days are additional sources of nuisance. The principal source of air pollution from open dumps occurs with the accidental or intentional burning of materials, resulting in smoke particles and gaseous products of incomplete combustion being released to the atmosphere. For reasons stated, open dumping of waste materials which will decay, burn, or release noxious odors is an objectionable procedure which contributes to air pollution and should, therefore, not be considered an acceptable means of refuse disposal.

Controlled Open Burning

The burning of waste materials dumped upon the surface of the earth or in open pits may be partially controlled by limiting the time of burning so as to minimize nuisances caused by adverse wind conditions or atmospheric temperature inversions. Control may further be exerted to the degree that objectionable waste components such as rubber may be disposed of other than by burning, while only certain select materials are burned in the open; nevertheless, open burning under controlled conditions is considered to be but one step removed from uncontrolled burning at open dumps, and, while it may reduce local nuisance complaints, it utilizes the atmosphere for disposal of incompletely burned gaseous and particulate combustion products. If limited areas are available for sanitary landfilling to the degree that controlled open burning seems necessary to conserve landfill space, it is suggested that at that time an incinerator should be constructed to effect a reduction in volume of the refuse under the more carefully controlled conditions obtaining in municipal incinerators.

Sanitary Landfilling

Where lands are available and suitable for burial of waste materials, sanitary landfilling, utilizing engineering processes of compaction and covering with inert material, can effect an economical means of waste disposal compatible with public health, esthetic, engineering, and air pollution requirements. Careful control must be exercised during sanitary landfilling operations; putrescible or odorous wastes must be promptly covered, thus preventing release of objectionable odors to the atmosphere. Earth cover will reduce the number of accidental fires; however, fire protection in the form of water storage, pumps, and fire hose is necessary at landfill sites to meet engineering standards for satisfactory operation. Gaseous products of decomposition, such as methane and carbon dioxide, will migrate slowly to the atmosphere through the cover of the fill; however, the quantity and character of the gases do not constitute air pollutional problems, although confinement of methane under building foundations may pose an explosion or fire hazard. Engineering study of possible water pollution hazards must be made for each sanitary landfill to protect against degrading of ground waters. Sanitary landfilling does not utilize the atmosphere for disposal of waste materials

and is, therefore, considered commendable for use by air pollution standards; however, its feasibility can only be established through engineering considerations of site locations, water pollution, and distance of waste material haul.

Part II—Waste Disposal by Salvage

Direct Utilization

Some of the wasted materials originating from homes, commercial houses and industries may be directly reused as raw goods for further processing. Examples are in the reuse of paper, paper products, and cardboard in the manufacture of corrugated boxboard and other such products. At metropolitan centers this becomes a sizeable enterprise, resulting in significant savings of raw materials and materially benefiting the economy of the corrugated paper and allied industries. Additional examples are the reuse of the iron from wasted food containers; the salvage of car bodies and other fabricated metal products; and the salvage of glass, both through direct reuse of bottles and as broken glass (cullet) for melting and reuse.

Every ton of waste paper, waste wood, or wood products, waste metal or glass that is salvaged represents a direct saving to the community in terms of raw material for industrial processing and an indirect saving to the community in that it need not be buried or burned at further cost. The economy of salvage operations is generally quite unpredictable and subject to the vagaries of the market so that salvage is more often successfully conducted by the private entrepreneur rather than by municipal or other public bodies.

The salvage of tin from "tin cans" was practiced to a limited extent during World Wars I and II, but has not proved profitable during periods of peace-time economy. The salvage of iron from metal food containers is profitably conducted in numerous places in the United States and may be expected to continue. At the present time the salvage of tin can and metal scrap from incinerator ash residues is becoming more prevalent in the United States. Under this process the burned can scrap is mechanically and magnetically separated from incinerator ash and after cleaning is ground into so-called "precipitation metal" for use in precipitating copper from copper mine waters or concentrates. This material reaches the copper mines in the form of irregular burrs of blued or oxidized iron which is especially adapted to enhance its value as "precipitation metal."

Sources of Air Pollution from Direct Utilization Processes

One of the most flagrant sources of smoke and odor from the direct utilization of wasted materials is in the open burning of car bodies preliminary to salvage. Numerous instances have been cited as to the adverse effects resulting from acrid smoke and fumes coming from such burning. Copper wire, tin, and chrome plating are often fused into the steel members, resulting in a degradation of the quality of the reclaimed iron. Preliminary stripping of car bodies is usually desirable to protect against the deleterious effects of these nonferrous metals; however, paint, grease, and undercoating are almost always removed by open burning, even when car interiors are carefully stripped. Because the open burning of car bodies results in gross air pollution, it is recommended that the open burning of car bodies should not be permitted, excepting at remote sites which are well removed from the possibility of creating an offense. Incinerators designed specifically for the controlled burning of car bodies have been designed and constructed such that air pollution criteria for incinerator discharges are met; unless such units are used, the burning of car bodies is considered an objectionable air pollutional contributor.

The salvage of paper, corrugated boxboard, wood, or wood products does not directly result in air pollution, except for that fraction of the waste that cannot be economically salvaged and which must be buried or burned. If burning of the fiber residue is accomplished in suitable incinerators operated under careful control, no objectionable degree of air pollution should result.

The salvage of metal cans for the ferrous metal nearly always involves a burning at temperatures of from 1200 to 1600°F to remove labels and destroy the residue remaining inside the can as a result of its original use. This firing can be accomplished without air pollution if done under controlled conditions in a properly designed two-stage incinerator.[1]

The salvage of glass involves no processes which contribute to air pollution, except possibly from the small quantities of paper labels that are usually removed by wet processes and are, therefore, more frequently buried than burned.

Salvage Through Hog Feeding

The feeding of garbage to hogs has long been recognized as a source of health hazard to humans and animals through the transfer of trichinosis as well as vesicular exanthema, a disease peculiar to swine; in both cases the use of crude garbage has been determined to be the disease vector. Recent laws in almost all of the states require the cooking of garbage to prevent the latter disease; a welcome by-product will be a reduction in trichinosis, a disease often transmitted to humans. It is anticipated that the cooking of garbage prior to hog feeding will have a salutary effect on the air pollutional aspects of the feeding of garbage to swine.

Hog ranches have long been recognized as principal offenders to the olfactory senses and instances have been cited where hog ranches of 50,000 to 70,000 hogs, feeding on crude garbage, have resulted in odor nuisances extending to distances of five miles or more from the hog ranch. Smaller ranches will ordinarily affect lesser areas. The principal source of objection to garbage-feeding hog ranches in the past has been the large amounts of putrid garbage which have been rejected by the hogs as food, and, mixed with the offal, have been piled up to decompose for possible future fertilizer usage. Recently adopted cooking techniques, accompanied by prompt burial of rejected food stuffs and offal, have reduced the air pollutional nuisance to the degree that isolation of a mile or more through proper zoning will usually afford adequate protection. It is recommended that if garbage-feeding hog ranches are to be considered satisfactory from an air pollutional point of view that they should conform with the following requirements:

1. That garbage be cooked in such a manner that the temperature throughout the mass will be held at 212°F for a minimum period of 30 minutes to effect sterilization and to stop putrefaction. The flash drying of garbage for hog feeding has also been practiced successfully in some communities; such garbage dehydration would offer the same protection against odor nuisances that would be realized through garbage cooking and simplifies problems associated with feed storage.
2. That cooked garbage should be fed on concrete aprons which can readily be cleansed of rejected food stuffs and offal by a thorough flushing with water.
3. That uneaten garbage and offal be buried daily and covered with at least one foot of earth or composted for fertilizer under such controlled conditions as outlined in the following section on Salvage by Composting.

Salvage by Composting

The production of a usable plant food supplement and humus by the composting of waste cellulosic fiber and

(*Continued on page 342*)

APCA'S 53rd ANNUAL MEET IN SPOTLIGHT

APCA's 53rd annual meeting in Cincinnati could not have been held at a more inauspicious time for attracting attention in newspapers and on radio and TV.

Consider: the break-up of summitry, Mr. K's frothings, puzzlement of Americans over the U-2 and the fate of its pilot, British efforts to mend humpty-dumpty diplomacy, starchy De Gaulle itching Russia, icy Adenauer resisting any Soviet defrosting, the U. S. presidential preliminary bouts.

All this headline grabbing made it seem quite impossible for APCA to hope for anything better than a polite but brief recognition of its existence.

Yet, for every major headline spotlighting the tense national and international temperatures, APCA managed to forge its own May 22–26.

If fumes of Russian oratory became hard to take, APCA's experts on automotive exhaust emissions served reminders that the motor cars, trucks, and buses in metropolitan centers continued to pose problems quite as sickening and dangerous.

If the U-2's achievements were partly unveiled, the Robert A. Taft Sanitary Engineering Center of the U. S. Public Health Service in Cincinnati laid claim to the use of its own pilotless "spy plane" to gather pollution data.

If the Central Intelligence Agency issued guarded reminders that espionage was, after all, part of its business in preserving American security, Cincinnati's Bureau of Air Pollution Control could point to its perfected scentometer as a device used successfully in tracking offensive odors to their source in the continuing battle for air purity.

Earth Remains Challenge

If the President could justifiably point with pride to startling photos of ground details from 70,000 feet aloft, Leonard Greenburg of New York, our retiring chief, reminded the nation that marvelous as the space age might be, there remained challenging earth problems within APCA's scope: new chemicals affecting foodstuffs, radio-active fallout, detergents in water supplies, and water conveying hepatitis, as discovered in India.

Reports and developments like these kept APCA on the front page and in radio and television news summaries. Besides the expansive communications media in the Queen City area, there were representatives of two press associations, the New York Times, Wall Street Journal, newspapers in Washington, Dayton, Louisville, and Indianapolis, and reporters for about a dozen magazines and technical journals frequenting APCA's pressroom.

Howison Was PR Chairman

Charles Howison of Cincinnati, whom APCA honored last year with an honorary membership for his conception and promotion of Cleaner Air Week, was public relations chairman, assisted by John Durrell of the Taft Center information office.

Press, radio, and television had been briefed on the entire proceedings about 10 days prior to the opening of the meeting. Authors of papers the press found particularly interesting were brought before reporters and TV cameramen.

It took a lot of doing to make matters like this and many more run as smoothly as they did, but everything clicked, including important fringe benefits like the daily authors' breakfast at 7:30 AM when those scheduled to appear on the day's program had a chance to fraternize and exchange views.

Committee Earns Praise

Well-deserved plaudits for these demonstrations of efficiency and open-handed courtesy went to the host committee under Charles W. Gruber, the conference chairman. Mr. Gruber, head of Cincinnati's Bureau of Air Pollution Control and Heating Inspection, had selected one of his staff, George Jutze, to be the chairman of general arrangements, with Ben Sachs as vice chairman.

Arthur C. Stern of Taft Center was technical program chairman, with George Minasian, APCA stalwart from Consolidated Edison Co. of New York as vice chairman, and the success of their efforts can best be gauged by the general comment of the 623 who registered for this 53rd meeting that it was APCA's best to date.

International Flavor

An international flavor was given by the presence as observers of seven West German technical experts and engineers, and by Humberto Bravo A, Mexico City's air pollution control chief, who presented one of the first papers.

The afternoon and evening of May 25 provided a break in the closely-spaced agenda. Scores of researchers, technicians, air pollution experts, and medical doctors took advantage of the tours of the Queen City area's major industrial plants where effective anti-pollution programs and installations were demonstrated. In the evening, a Gay Nineties banquet and review (absolutely no speeches; just good food and top-flight entertainment) climaxed a memorable day.

◆ ◆ ◆

Meantime, the ladies had not been forgotten. Mrs. Charles W. Gruber, wife of the conference chairman, had enlisted the talents of other local wives (Mesdames Howison, Jutze, and Stern) who headed various groups to accommodate the feminine visitors at the meeting.

Distaff Side Kept Busy

There was the daily kaffee klatsch, where the ladies gathered each morning for briefing on facets of their program and to renew friendships with those they had met at previous APCA meetings. Highlights of the ladies program included bus tours of Cincinnati's famous suburban areas, a luncheon at the Art Museum and an inspection of the galleries, tours of famous downtown churches noted for their architectural beauty, and a tea at Taft Museum which is famous for its magnificent art collection.

After Harry A. Belyea, chief air pollution control officer of Metropolitan Toronto (Canada) had taken over the gavel as APCA's new president, he looked with a great deal of satisfaction at the accomplishments of the five days spent in Cincinnati, and predicted that the following year would witness much closer collaboration with foreign countries, along with a membership gain of about 50%.

Mr. Belyea said that he and his fellow-officers considered the Cincinnati meeting the most successful and fruitful in APCA's history. He added that it appeared that automotive exhaust research would continue to get a lot of attention from APCA's dedicated members, but he emphasized that all forms of air pollution still would be targets of our organization.

PICTORIAL HI-LITES OF ACTIVITIES AT

SIGNING UP—A must at every meeting is the registration desk where registrants get acquainted.

CANDID CAMERA—Cameraman catches informal shots while taking in the various meeting sights.

KEY PEOPLE—C. W. Gruber, G. A. Jutze, and J. F. Byrd mak plans.

HIGH NOON—Meeting-goers enjoy fun, food, and fellow the Pr

...T APCA'S 1960 ANNUAL MEETING

rd ma... plans.

AWARD PRESENTATIONS—Awards were presented to the following: *(from left)* Dr. Robert A. Kehoe receives the Richard Beatty Mellon Award which is presented to him by James A. Carter; Dr. William A. Hamor, who was unable to attend the annual meeting, is awarded honorary membership in the Association, which is accepted by Arnold Arch; also an APCA honorary membership is bestowed on Thomas C. Wurtz as presented by Mr. Carter.

fellow... the Presidents' luncheon while attending the meeting.

For The Ladies—The Ladies of APCA were not forgotten. A daily kaffe klatsch, sightseeing tours, a luncheon at the Art Museum, church tours and a tea at Taft Musuem were among the ladies' events.

Ontario Becomes New Section of APCA; E. W. Anderson To Head Group in '60-'61

At a dinner meeting held at Malloney's Studios April 26, a group of men representing Municipal and Provincial Control Officers, Federal, Provincial, and Municipal Pollution Officers, representatives from industry and institutions, as well as consultants and suppliers, a section known as the Ontario Section of the Air Pollution Control Association was formed. This section was recognized by the APCA Board of Directors May 23 and is now in acton.

The membership includes for the most part Central Ontario, and Metropolitan Toronto and does not infringe on the Niagara Section membership.

The following were elected officers for the year 1960–61.

E. W. Anderson, Chairman, Etobicoke Civic Advisory Committee, Vice-Chairman, Metropolitan Toronto Civic Conference; David Bronstein, Vice-Chairman, Markad Company, Toronto, National President of Canadian Conference of Zionist Societies; Douglas P. Knight, Acting Secretary, Industrial and Institutional Accounts, Airkem Sales and Service, Canada, Member APCA; Harvey Singer, Treasurer, Chemical Engineer in Research on Air Pollution, Ontario Hydro-Electric Power Commission; A. M. Norling, Director, American Air Filter of Canada; A. C. Elliott, Director, Superintendent of Utilities Department, Steel Company of Canada, Hamilton, Ontario; D. H. Matheson, Director, Director of Municipal Laboratories, City of Hamilton, Ontario; D. A. Thomas, Director, Physicist Air Pollution Control, Department of Health, Ontario; H. L. Walker, Director, Process Engineer, British American Oil Company Ltd.; Noel Seager, Director, Director Plants Operation, Toronto, Board of Education; Charles Newbury, Director, Associate Consultant on Air Pollution and Combustion, Research Development and Survey Associates, Toronto, Ontario.

Promote Understanding

The purpose of a section is to promote a better understanding of the problems of atmospheric pollution between control officials, research personnel, educators, representatives of industry, and consultants within the geographic area of each section, and to provide a means for the interchange of scientific information and technical methods aimed towards solving these problems.

Seventy-five were in attendance and enthusiasm was at a peak. This is the second section of the Air Pollution Control Association to be formed in Canada.

One highlight of the meeting was the announcement that Harry Belyea, Air Pollution Control Officer of Metropolitan Toronto, had been elected President of the U. S. Air Pollution Control Association, and this represents the second time that a Canadian has been so honored.

Expressions of good wishes were received from Honorable Roland Michener, Miss Margaret Aitken, M.P., and D. Walker, Minister of Public Works.

Regular monthly meetings will be held, at which guest speakers will deal with air pollution problems and their solution. Different phases of air pollution will be discussed each month.

NEW CHAIRMAN ELECTED

San Francisco architect William B. McCormick was unanimously elected chairman of the Bay Area APCA Advisory Council for the fiscal year beginning July 1. Other newly elected council officers are vice chairman Dennis R. Cronin, senior staff engineer for Columbia-Geneva Steel Division in Pittsburg, and Lawrence Livingston, Jr., a San Francisco city and regional planning consultant, who will serve his third term as secretary.

Personalia

H. K. Kugel, past president of APCA, retired from the District of Columbia where he inaugurated a new Division of Smoke Regulation pursuant to Public Law No. 279, 74th Congress, approved in August, 1935. After his compulsory retirement, Mr. Kugel was re-employed and holds the title of Research and Standards Engineer.

* * *

Charles W. Lockhart has been appointed Vice President of Sales by the Buffalo Forge Company, effective May 20, 1960. Mr. Lockhart joined the company's engineering department in 1936, was Manager of the firm's San Francisco Sales District from 1945 until 1953, and most recently has served as Sales Manager of the Air Handling Division.

* * *

Albert W. Locuoco has been appointed Commissioner of the Cleveland Division of Air Pollution Control; he was formerly chemist and Bureau Chief and he succeeded LeRoy Diehl.

* * *

Dr. Seymour Calvert, Associate Professor of Chemical Engineering at Case Institute of Technology, has been appointed chairman of the newly formed Air Pollution Advisory Board

(*Continued on p. 313*)

W. Germans Visit APCA Headquarters

CLEARING THE AIR—Six West German chemists and engineers visited APCA Headquarters in Pittsburgh. Pictured from left are: (seated) Arno Wiegand, Hermann Hoeppli, and Arnold Arch, APCA'S Executive Secretary; (*standing*) Helmust Locke, Otto Peter Guepner, Klaus Emicke, and Alfred Rokocki.

DEVELOPMENTS *in the* USE *of the* A.I.S.I. AUTOMATIC SMOKE SAMPLER*

JONG C. PARK, Chemist, Nashville Study,
DONALD M. KEAGY, Chief, Field Studies, and
WILLIAM W. STALKER, Supervisor, Nashville Study, State and Community Services, Public Health Service, and
U. S. Department of Health, Education, and Welfare, Cincinnati, Ohio

The rationale for describing particulate air pollution in terms of its soiling effect upon surfaces has been amply developed.[1, 2] Several methods and instruments for measuring the extent of this soiling effect have been described.[3, 5, 6] In the most commonly used procedure air is drawn through a strip of filter paper by a sampler known as the A.I.S.I. (American Iron and Steel Institute) Automatic Smoke Sampler. The optical density of the resulting spot (particulate deposit) on the filter paper is determined by measuring light transmission through the spot, and is expressed in Coh units per 1000 linear feet of air.[2]

In a special air pollution research study now being conducted at Nashville, Tenn. by the Public Health Service A.I.S.I. samplers have been in continuous use for almost one year at 11 of the 123 sampling stations. It was noted early in the Nashville study that:

1. There was a variation in air flow rates between different rolls of filter paper.
2. There was a significant difference between initial flow rates of the samplers.
3. The flow rate of air through any one spot of a filter paper decreased as much as 20% within a two-hour sampling period.
4. To obtain comparable results between the samplers, each sampler had to be calibrated and the average rates of air flow determined for each sampler.

The variations in flow rate through clean paper were possibly due to variations in the diameter of the filter fibers or to the density and thickness of the filter paper. The flow rate decrease during the sampling period may be due to the accumulation of particles on the filter paper or to variations in the physical and chemical characteristics of the particulate matter.

Two modifications of the samplers were made by (1) substituting an Industrial Timer for the timing rotor and (2) installing a contact switch (to the left of the sampling head) to control the automatic positioning of the filter tape such that the sample spots would be equally spaced at two-inch intervals (Fig. 1).

The sampling tape is 1.5 in. wide Whatman #4 filter paper. One-eighth in. diameter indexing holes located adjacent to one edge, and spaced two inches apart, enable the contact switch to position the tape.

Automatic Spot Evaluator

An automatic spot evaluator (Fig. 1), designed and built by Research Appliance Company, was utilized in this study to read automatically the percent transmission of the four to five thousand samples collected each month at Nashville. The instrument employs a 120-volt, 6-watt light source and a $1^1/_8$ in. diameter selenium voltaic photocell. Two electrical contact switches, similar to the one on the sampler, utilize the indexing holes in the tape to position automatically and accurately, first, a clean spot and then a sample spot under the light source.

The output signal from the photocell is amplified and fed to a servo motor, whose action is translated into indicated and recorded digital figures. If the indicated reading for a clean spot on the filter tape is 100%, plus or minus two, the instrument goes into the recording cycle wherein the sample is moved into position, is "read" by the instrument, and the index number and

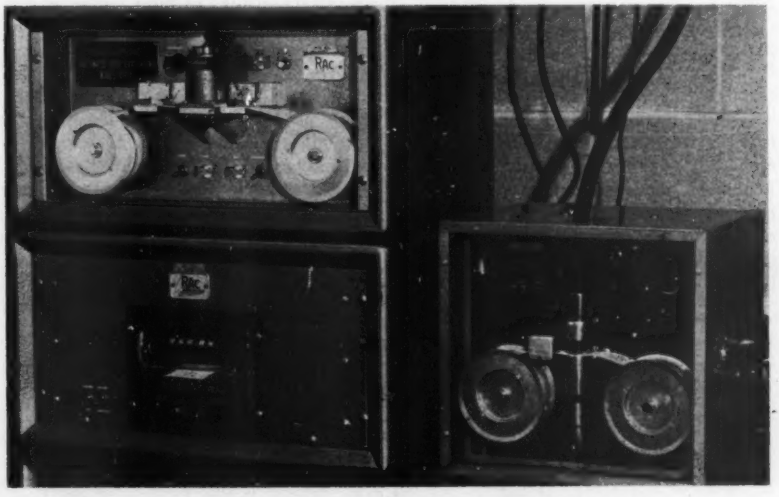

Fig. 1. Automatic spot evaluator and AISI sampler.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

Fig. 2. Walk-in sampler shelter.

percent transmission for the sample are printed on a paper tape. If the indicated reading is outside the limits of 98–102, the intensity of the light source is automatically adjusted to bring the percent transmission within the limits and the instrument again goes into the recording cycle. This automatic evaluator reads approximately 12 sample spots per minute and requires a minimum amount of work to start the instrument and to change tapes. Reproducibility was tested by running a tape of 40 samples through the evaluator five times, and it was found to be within approximately two percentage units. The mean deviation from 168 readings obtained with a Research Appliance Company manual spot evaluator (Model 157) was 3.5% transmission. The readings were nearly always higher than the manual evaluator readings and it is believed that this deviation will be explained, or by instrument adjustment, reduced substantially.

Sampling and Flow Measurement Techniques

The samplers located at the 11 sampling stations are housed in walk-in shelters (Fig. 2). The sampling probe, which is half-inch copper tubing, enters through the side of the shelter and the downstream end is connected to the stainless steel sampling head with a piece of rubber tubing to provide flexibility when the sampling head moves up and down during the repositioning period.

The sampler utilizes a 30 rpm diaphragm-type pump which gives pulsating flow. To measure the flow rate through the clean and soiled spots, a dry test meter (capacity—0.1 cubic feet per revolution) was connected immediately upstream of the sampler. Leakage of air between the sampler and the meter is minimized with this arrangement and was considered negligible. In measuring the average flow rates, the volume of air sampled was equal to two or three complete revolutions of the dry test meter.

Flow Rate Variation Through Clean Filter Paper

The flow rates through each of two clean areas on four rolls of filter paper, selected at random, were measured twice (Table I). Analysis of the data showed that there was a significant difference in flow rate between the rolls of filter paper, but that the variation within the roll was not significant at the 95% confidence level.

In a similar manner it was determined that there was a statistically significant variation in the readings of percent light transmission between rolls of clean filter paper. The standard deviation of percent light transmission readings within a roll of clean tape was 2.41.

Flow Rate Variation Between Samplers

The air flow rate through clean filter paper (initial flow) was measured for ten sampling units using the same area of a filter paper (Table II).

Table II—Flow Rate Through Clean Filter Paper for Ten Samplers

Sampler Number	Initial Flow, cfm
1	0.400
2	0.369
3	0.308
4	0.376
5	0.385
6	0.367
7	0.329
8	0.303
9	0.317
10	0.400

The above results indicate an apparent variation in the initial flow rates between the 10 samplers. To establish the statistical significance of this difference, 15 clean areas were selected, from several rolls of filter paper, which gave exactly the same percent transmission readings, minimizing the error due to the inherent differences in the clean filter paper. Two of the samplers were used to measure the flow rate through each area (Table III).

Analysis of the data in Table III shows that the difference between the two sampling units is highly significant. However, for any one sampling unit, the flow rates apparently are not too greatly different.

Table III—Flow Rate Through 15 Clean Filter Paper Areas Having Identical Light Transmission Readings

Run No.	Sampler No. 1 (cfm)	Sampler No. 2 (cfm)
1	0.359	0.387
2	0.360	0.387
3	0.357	0.385
4	0.360	0.385
5	0.362	0.385
6	0.362	0.384
7	0.362	0.382
8	0.359	0.374
9	0.361	0.377
10	0.358	0.377
11	0.360	0.373
12	0.365	0.381
13	0.365	0.377
14	0.365	0.372
15	0.370	0.375

Flow Rate Variation During Sampling Period

Figure 3 is an illustration of the decrease in flow rate during a two-hour period for two samplers which simultaneously sampled an atmosphere wherein the dust concentration was equivalent to 0.707 Cohs per thousand feet. It is to be noted that the slopes for the two curves are the same, but each has a different initial flow rate. The slope is a function of the dust concentration; a steeper slope could be expected for higher concentrations.

To calibrate an A.I.S.I. sampler, it is necessary to know the relationship between percent transmission (T) and Cohs/1000 linear feet. The Coh unit/1000 feet allows comparison of different samples of particulates regardless of the area of the sampling spot, duration of sample, or sampling flow rate, and is defined as follows:

$$\text{Cohs/1000 ft.} = \frac{D \times 10^5}{L} = \frac{\log 100/T \times 10^5 \times A}{\theta \times \bar{q}} \quad (1)$$

where:

D = Optical density = $\log 100/T$
L = Linear feet of sampled air = $\theta \times \bar{q}/A$
T = Percent light transmission
A = Area of sampled spot in square feet
θ = Sampling time in minutes
$\bar{q}$ = Average flow rate for sampling period in cfm

Since the Coh unit is related to the average flow rate for the sampling period ($\bar{q}$), and since T is a function of optical density (D) and all other items of the equation are constants if the sampling duration is kept uniform, the desired calibrated curve of Cohs/1000 ft. vs T can be developed if the relationship between $\bar{q}$ and D can be established.

Table I—Air Flow Rates Through Clean Filter Paper (cfm)

Spot No.	Filter Paper Roll No. 1	No. 2	No. 3	No. 4
1	0.308	0.357	0.383	0.353
	0.313	0.366	0.370	0.350
2	0.367	0.359	0.370	0.344
	0.359	0.376	0.385	0.350

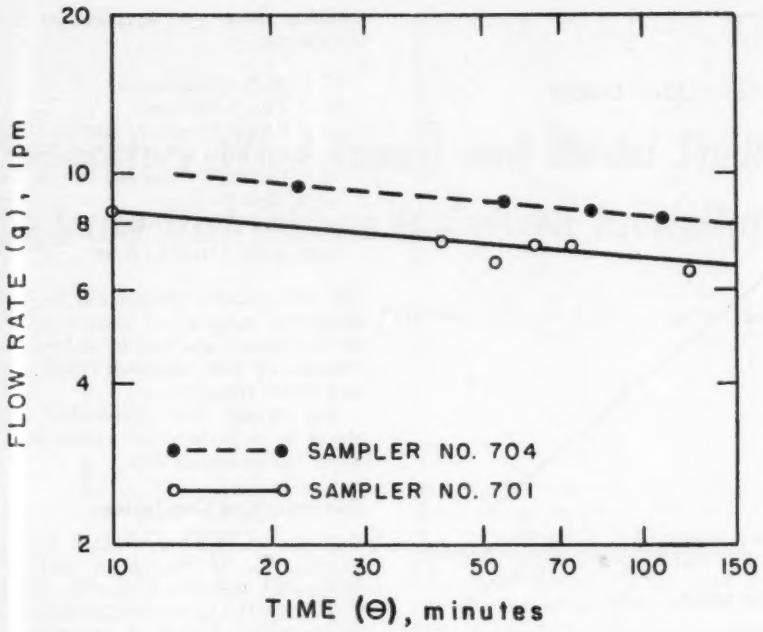

Fig. 3. Flow-rate variation during sampling period.

Ten A.I.S.I. samplers were used to establish the relationship between flow rate and optical density. For each of these ten samplers 39 stained spots and 16 clean spots were used to establish the above relationship. The results from one series of runs for one A.I.S.I. sampler are shown in Table IV. The average of the readings for the 16 clean spots is presented as the reading for 100% transmission.

The anticipated linear relationship between optical density and flow rate through the filter paper was fairly well demonstrated when the results for the ten A.I.S.I. samplers were plotted. One of these 10 plottings is shown in Fig. 4. To establish the regression line for this plot, the least squares method was used and the line is represented by:

$$q = 0.396 - 0.163 \times D \qquad (2)$$

Therefore, the general equation for the regression lines is:

$$q = q_0 + kD \qquad (3)$$

where:

q_0 = Initial flow rate
k = Slope of regression line

The terms of the regression line equation for the data obtained from the 10 A.I.S.I. samplers are shown in Table V.

Table IV—Percent Transmission and Optical Density Vs Flow Rate for A.I.S.I. Sampler No. 1

T	D	q	T	D	q
100	0.00	0.400	65	0.19	0.367
88	0.06	0.388	64	0.19	0.358
85	0.07	0.374	63	0.20	0.353
84	0.08	0.383	62	0.21	0.342
84	0.08	0.381	62	0.21	0.363
84	0.08	0.378	60	0.22	0.368
77	0.11	0.371	60	0.22	0.360
76	0.12	0.377	57	0.24	0.355
76	0.12	0.376	57	0.24	0.363
74	0.13	0.385	54	0.27	0.352
73	0.14	0.366	54	0.27	0.351
73	0.14	0.365	54	0.27	0.336
72	0.14	0.360	51	0.29	0.343
70	0.16	0.372	48	0.32	0.354
70	0.16	0.359	44	0.36	0.343
69	0.16	0.365	39	0.41	0.330
68	0.17	0.377	38	0.42	0.328
67	0.17	0.367	38	0.42	0.320
67	0.17	0.354	30	0.52	0.313
65	0.19	0.359	28	0.55	0.332

Table V—Regression Line Equation Terms

Sampler Number	q_0	k
1	0.395	−0.162
2	0.367	−0.176
3	0.308	−0.148
4	0.377	−0.168
5	0.379	−0.143
6	0.368	−0.173
7	0.325	−0.147
8	0.298	−0.155
9	0.313	−0.155
10	0.398	−0.144

Sampler Calibration

Comparing samples collected in Nashville during the summer and the winter, the values for the slope in equation 3 were not significantly different for the respective seasons.

Although Table V shows that the slope (k) varied for each sampler, a statistical evaluation showed that the differences between the slopes were not significant compared with the extent of scattering around the regression line. Therefore the average value of the slopes, −0.158, was accepted as the best estimated value and equation 3 was rewritten as:

$$q = q_0 - 0.158 \times D \qquad (4)$$

Given the initial flow rate (q_0) for any sampler and the optical density of any sampled spot (D), the final flow rate through the spot (q_f) can be calculated and subsequently the average flow rate ($\bar{q}$) can be determined from the equation:

$$\bar{q} = \frac{q_f + q_0}{2} = \frac{(q_0 - 0.158 \times D) + q_0}{2} = q_0 - 0.079 \times D \qquad (5)$$

For greatest accuracy, q_0 should be determined for each roll of tape; the mean of readings of three areas selected at random would be adequate. Assuming that the particulate concentration in the atmosphere remains constant during the sampling period, equation 1 may be modified as follows:

$$\text{Cohs/1000 ft} = \frac{\log 100/T \times 10^5 \times A}{\theta\,(q_0 - 0.079\,D)} \qquad (6)$$

The following is an example cal-

Table VI—Cohs/1000 ft for Various Percent Transmission Readings

T	D	Cohs/1000 ft
100	0.00	0.0
90	0.04	0.5
80	0.09	1.1
70	0.15	1.8
60	0.22	2.6
50	0.30	3.6
40	0.39	4.9

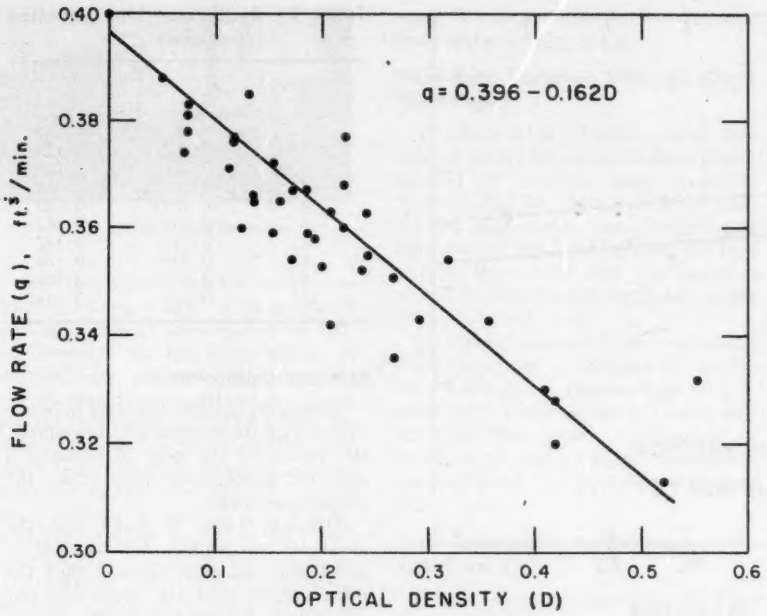

Fig. 4. Flow rate vs optical density of AISI sampler.

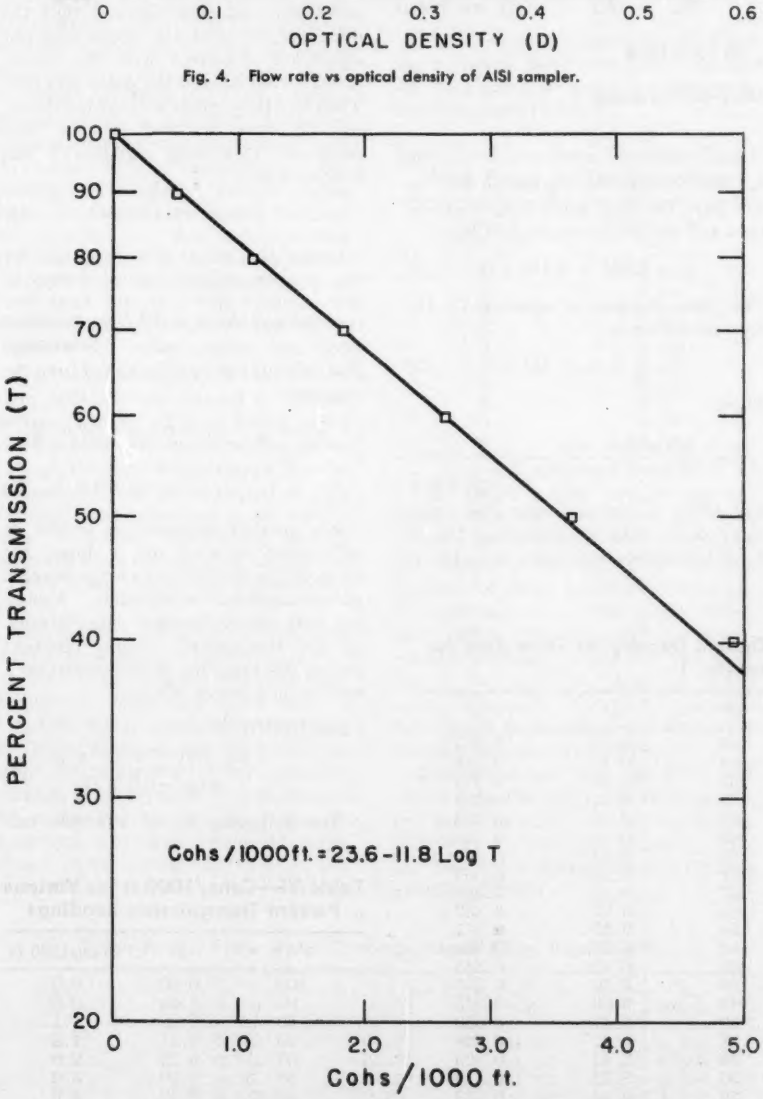

Fig. 5. Conversion of percent transmission to cphs/1000 ft for one AISI sampler.

culation using this equation for the conditions:

T = 50 % transmission
θ = 2 hr = 120 mins
A = 0.0054 ft² (dia. of spot = 1 in.)
q_0 = 0.396 cfm
$D = \log 100/T = \log 100/50 = 0.301$
Cohs/1000 ft =

$$\frac{0.301 \times 10^5 \times 0.0054}{120\,(0.396 - 0.079 \times 0.301)} = 3.640$$

The Coh values corresponding to various other readings of percent transmission for the same sampler and sample duration (θ) were calculated (Table VI) and plotted (Fig. 5).

The straight line relationship was found to exist only for values of T above approximately 50%.

Summary and Conclusions

Eleven A.I.S.I. automatic smoke samplers are in continuous and simultaneous operation as part of a year-long Public Health Service field study in Nashville, Tenn. The heavy load of reading so many tapes prompted the development of an automatic spot evaluator which can read approximately 12 samples per minute.

Tests revealed that the flow rate varied significantly between samplers and between filter tape rolls, and that the flow rate decreased at a predictable rate during the sampling cycle. The variation in flow rate of areas within the roll was not significant for the tape used in this study.

An A.I.S.I. sampler calibration procedure was developed which is both simpler and more accurate than previous procedures.

Acknowledgment

The authors acknowledge the assistance and constructive criticism provided by fellow staff members.

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Laboratory Wind Tunnel and Model Studies to Improve Gas Velocity Distribution in Cottrell Precipitators*

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In an ideal precipitator, the gas velocity at all points within the electrode system should be equal in magnitude and should be directed from the inlet toward the outlet. In practice, the gas is delivered to the precipitator by a duct or flue, or the gas may enter the precipitator directly from a cyclonic collector or other device placed immediately ahead of the precipitator. The general problem to be treated in this paper is how to control and modify the incoming gas stream—which is usually characterized by turbulence and widely varying velocities poorly distributed and wrongly directed—in such a way as to approach the ideal uniform gas flow desired within the precipitator. In addition, it is highly important to minimize the pressure difference required to force the gas through the precipitator and associated ducts at the desired rate of flow. Supplementary requirements are that the gas velocity in the hoppers and in the maintenance space above the electrodes should be kept down to values small compared to those in the electrode system.

This problem may be approached from the general viewpoint, where attention is concentrated on the guiding rules to be followed in achieving good gas flow distribution in the precipitator for a few configurations of the inlet duct which occur repeatedly when, say, 100 typical commercial precipitators are considered. For example, one may establish an acceptable means for achieving good gas flow distribution in a precipitator when it is a part of a combination unit with a Multiclone or multiple tube cyclone ahead of it. For brevity, such a Multiclone-precipitator combination will be called a "CMP unit."

The problem may also be approached as a particular case for each individual job, on the assumption that measures which proved helpful in the last job may be harmful in the present one. For this approach, experiments with a scale model of each job are necessary in order to achieve the desired gas flow distribution. Minor variations in the flue layout or other equipment, such as, for example, an air preheater, which may precede the precipitator, introduce unknown variables which are studied individually for each job.

The approach from the general viewpoint was taken as a guide during the experimental program conducted in Western Precipitation Laboratories in the years 1948–51. In this work, models of precipitators with various inlet configurations encountered frequently in practice were built and tested on a rather large scale—up to $^3/_8$ of full size in some cases. A six-foot man could walk around inside of these models without stooping and arrange the electrodes, vanes, screens and other devices in any way he might care to, and for want of a better term, they were referred to in the Western Precipitation organization as "wind tunnel tests."

In recent years, the model tests have been guided from the other viewpoint where each job has been regarded as a special case, and here most of the models have been constructed on a scale of $^3/_4$ inch in the model being equivalent to one foot in the actual installation; that is, the model is $^1/_{16}$ of actual size. These comparatively small models have been constructed of transparent plastic so that the experimenter could make measurements and changes inside with full visibility.

Dynamic Similarity in Fluid Flow

Whenever the flow of a fluid through a model is being studied, there must be some assurance that the flow pattern in the model will closely correspond to the actual flow pattern in the full-scale unit. A thorough discussion of this point will easily fill a 300 page book,[1] but most of the essentials for the present account may be reduced to a paragraph or two. In order to attain the desired similarity, one may attempt to keep the Reynolds number for the flow in the model equal to the Reynolds number for the flow in the full-scale unit. The Reynolds number is a dimensionless ratio between the inertial and viscous forces existing in the flow pattern. The Reynolds number, R, is defined as

$$R = \rho v L/\mu \qquad (1)$$

where ρ is the density of the fluid, v its velocity, and μ its viscosity. L is

Fig. 1. Large-scale model of precipitator with inlet duct axis coinciding with precipitator axis.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

Fig. 2. Large-scale model in which gas reaches inlet flowing at right angles to precipitator axis.

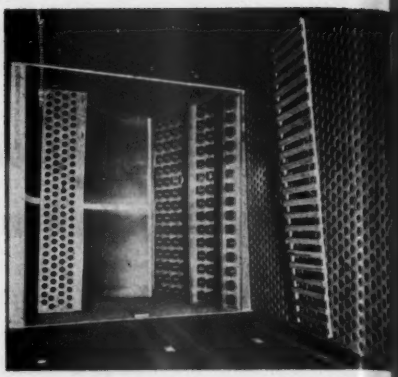

Fig. 3. Interior view of large-scale model of a "CMP unit" looking toward the inlet.

the "characteristic dimension" involved. If the fluid is flowing through a circular duct, L is its diameter; if through a rectangular duct, L may be taken as its width, although some authorities take L as four times the "hydraulic radius" in this case; or if the fluid is flowing around a sphere in its path, L is the diameter of the sphere. A consistent system of units must be used so that they will cancel out properly in calculating R, even though it is a dimensionless ratio.

When R is less than 2000, the flow is normally laminar or streamline; when R exceeds 4000, the flow is normally turbulent. Between 2000 and 4000 is a transition region. The flow of the gas through commercial precipitators at normal load is practically always turbulent, so in conducting model studies it is essential to maintain the Reynolds number above 4000, even if it is not considered desirable or possible to make the Reynolds number in the model equal the Reynolds number in the actual unit.

In the large-scale models already mentioned, where a man could walk inside, it was possible to keep the Reynolds number in the model equal to the Reynolds number at the corresponding location in the actual unit, and the tests were conducted under these ideal similarity conditions. In the recent experiments with $^1/_{16}$th scale transparent plastic models, L in the actual unit is 16 times L in the model. Air at room temperature is used as the fluid in the models usually, although some tests have also been conducted with water, using models appropriately designed for water. The industrial gases flowing through a commercial precipitator normally have a density, ρ, and viscosity, μ, of the same order of magnitude as ρ and μ for the air in the model. Therefore, to maintain the same Reynolds number in the $^1/_{16}$th scale model as in the actual unit, the velocity of the air, v, in the model must be roughly 10 or 20 times greater than it is in the actual unit. Since the gas velocity in industrial flues is commonly of the order of 50 feet per second, the corresponding velocity in a $^1/_{16}$th scale model would be of the order of 500 or 1000 fps. This would call for a quite powerful fan and the plastic walls of the model would have to be quite thick and heavy to be strong enough to withstand the pressure differences associated with such high gas velocities. The usual practice with $^1/_{16}$th scale models, therefore, is to use lower velocities than those required for equal Reynolds numbers, and merely keep the Reynolds number in the model above 4000 at the lowest.

If water is used in a model, its density, ρ, and viscosity, μ, are of the order of 1000 times and 50 times the corresponding values for the gas in the precipitator. Since 1000/50 is 20, it follows that for a $^1/_{16}$ scale model, the velocity of the water would be of the same order of magnitude as the gas velocity in the actual unit in order for the Reynolds numbers to be equal in model and actual unit. Although a gas velocity of 50 fps in a duct is routine, a water velocity of 50 fps in an open model of the duct is inconveniently high. Here again, therefore, the tendency is to merely keep the Reynolds number above a minimum of 4000.

Studies with Large-Scale Models up to 3/8 Full Commercial Size

The most common form of Cottrell precipitator consists of a rectangular shell filled with electrodes usually in the form of flat plates suspended vertically and parallel to the direction of gas flow, which is usually horizontal. The gas velocity within the precipitator should be uniform and normally is designed to have an average value between 3 and 10 fps. The gas enters and leaves the precipitator usually through flues of much smaller cross-section than that of the precipitator shell, and in the flues the gas velocity is usually of the order of 30 to 60 fps. Stringent space requirements in most commercial installations make it impossible to build scientifically desirable transitions diverging at a small angle such as 8°. Consequently an abrupt transition must often be built, and then the resulting poor gas flow distribution must be corrected by means of vanes, baffles, perforated plates, or other devices of this type.

Figure 1 is a photograph of a large-

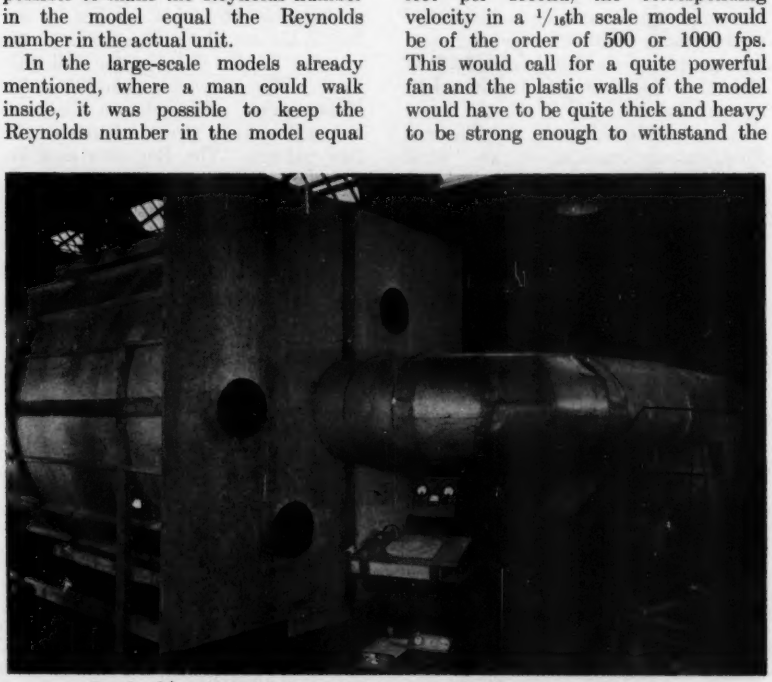

Fig. 4. $^3/_8$ scale model of a typical pipe-type blast furnace precipitator.

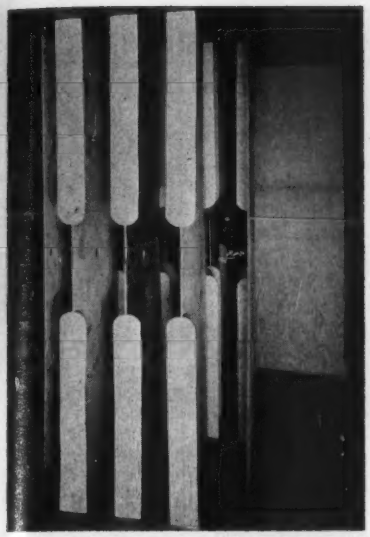

Fig. 5. Interior view of large-scale model showing one type of plate electrode being tested.

scale model built to investigate the case where the axis of the inlet duct coincides with the axis of the precipitator. In this model, the inlet duct was two feet square, and the model of the shell was six feet square. The transition connecting them was only two feet long, so that its walls were inclined at 45° to the axis. The cross sectional area of the precipitator model was thus nine times that of the duct, a ratio close to that existing in typical precipitator installations.

Figure 2 is a photograph of another large-scale model arranged so that the "gas" (air in the model) reaches the precipitator inlet flowing in a direction perpendicular to the precipitator axis. In an actual precipitator, this would represent a case where the gas comes up from below or down from above, or comes in transversely from the left or right, and this is probably the situation that occurs oftenest in commercial practice. Figure 3 is a photograph taken inside of another large-scale model of a precipitator, looking toward the inlet, which in this case was directly connected to the outlet of a model of a Multiclone; in other words, this is an interior view of a large-scale model of a "CMP unit." The "gas" (air) leaving the Multiclone issues through 135 pipes seen in the photograph, each of which was provided with a "spinner" to cause the air to flow spirally and issue from the pipe with a spinning motion, just as it does in an actual unit. Some of the model perforated plates and other devices tested as corrective measures for the air flow are seen in the photograph.

Figure 4 is a photograph of a $^3/_8$ scale model of a blast-furnace precipitator. This was a pipe-type precipitator in which the gas flowed vertically upward through parallel pipes each containing a high voltage electrode wire along its axis, the collected material on the inner walls of the pipes being removed by continuous flushing with water running down the inner walls as a film. This model had 250 pipes and was built in a horizontal position because this made its building and testing easier. The horizontal position did not affect the flow of air through the model at all, although a horizontal position for an actual precipitator of this type would be absurd.

Figure 5 is another interior view of a large-scale model in which various types of plate electrodes were being tested to determine the nature of the gas flow between them. In this particular instance, the plate electrodes were provided with dust shields extending down from the top and up from the bottom but leaving a gap in the center, an arrangement which was desirable from the standpoint of convenient construction of the high voltage electrodes which must be supported between the grounded plate-type collecting electrodes. The model tests showed, however, that the use of dust shields with a gap in them is undesirable because the gas velocity through the gap is excessive.

At the time of this work, suitable hot-wire anemometers for this type of experiment could not be purchased, so a special one was designed and built. Figure 6 is a photograph of the instru-

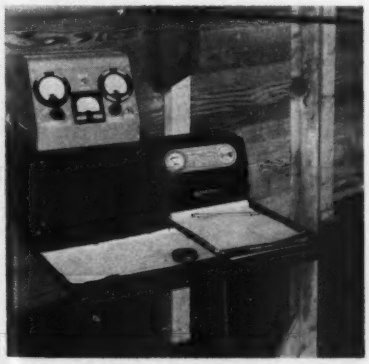

Fig. 6. Special hot-wire anemometer used in large-scale model tests.

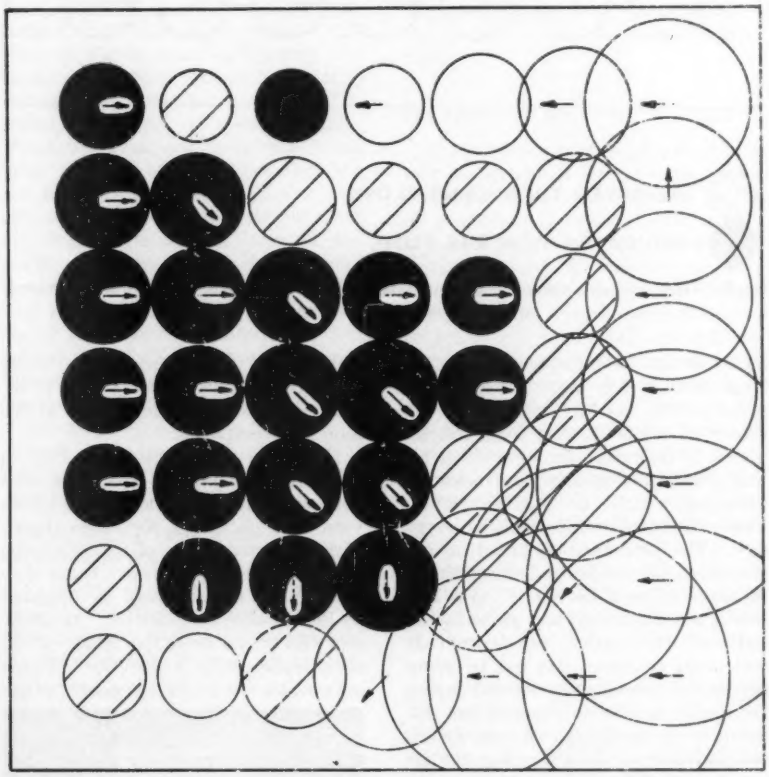

Fig. 7. Typical diagram representing anemometer data obtained from 49 points in a transverse test plane when gas distribution is poor.

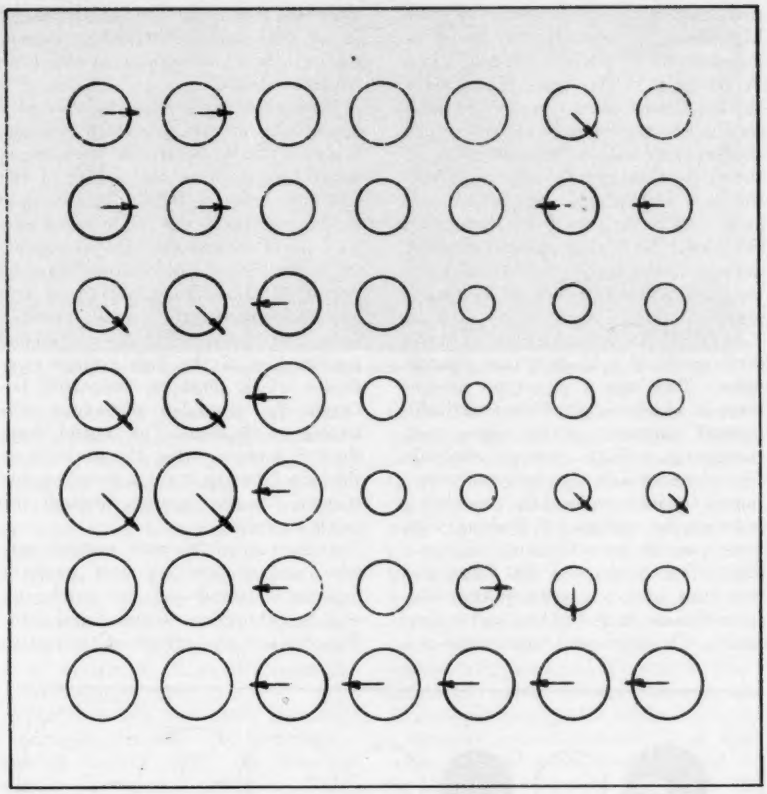

Fig. 8. Typical diagram representing anemometer data obtained from 49 points in a transverse test plane when gas distribution is good.

ment set up for measurements in the large models. It was calibrated by placing the hot-wire probe at the center of a pipe 12 feet long and six inches in diameter, through which air was drawn at a steady rate measured accurately with a Venturi orifice. The calibration was re-checked every day. The probe was mounted on the end of a long wooden rod resembling a broomstick, seen in Fig. 6, and this was inserted through test ports in the walls of the model, as shown. It was usual to insert this rod to seven different points equally spaced across the model, and to do this at seven different levels equally spaced between the top and bottom, thus mapping the air speed at 49 different points in a transverse plane of the model. This was usually done for at least four different planes, and sometimes as many as eight.

The hot-wire anemometer did not yield any information about the direction of flow at all of these points, so the directional information was obtained by inserting a similar wooden rod with a spike on its end, having a small tissue paper ribbon attached to the end of the spike, this likewise being placed at the numerous test points.

Figure 7 is an example of the diagram prepared to represent the data thus obtained from the 49 points in a transverse test plane. A circle was drawn with its center at one of the 49 points, the diameter of the circle being proportional to the air speed as indicated by the hot-wire anemometer. An arrow was also drawn from the center of the circle outwards in a direction coinciding with the transverse component of the air velocity at that point, as indicated by the tissue-paper probe. The observer is assumed to be looking upstream, or from the precipitator outlet toward the inlet. If the flow direction were purely longitudinal, with no transverse component, no arrow was used in the diagram for that point. If the longitudinal flow were in the wrong direction, that is, from outlet towards inlet, the circle for this point in the diagram was filled in to make it solid. Since Fig. 7 shows numerous

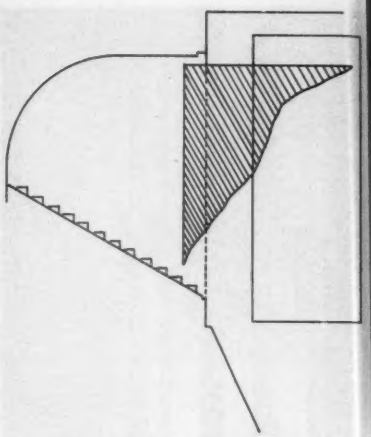

Fig. 9. Plot in side elevation of gas velocity distribution in a commercial "CMP unit" before corrective devices were installed.

solid circles, and a wide variation in the size of the circles, it represents a very poor distribution of the gas velocities in the transverse tests plane which it represents. Figure 8, on the other hand, shows only open circles of reasonably uniform size, and consequently it represents a good distribution of the gas velocities in the test plane it represents. This might be a different test plane, or the same test plane after proper correction of the air flow by suitable devices correctly arranged.

From these large-scale model studies evolved some general guiding rules to be followed in designing commercial precipitators of various common types with usual configurations of the flues and other devices bringing the gas to the precipitator inlet. When the results of these model tests were applied to full-scale units, the improvement in gas velocity distribution was indeed gratifying. Figure 9 is a plot of the gas velocity distribution in a vertical longitudinal plane in the inlet section of a commercial precipitator which was

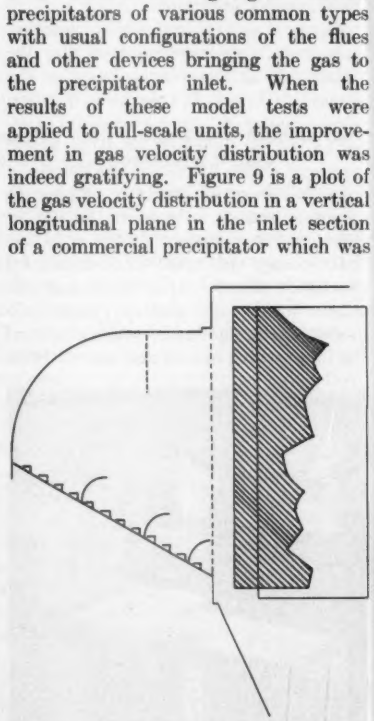

Fig. 10. Plot in side elevation of gas velocity distribution in a commercial "CMP unit" after corrective devices were installed.

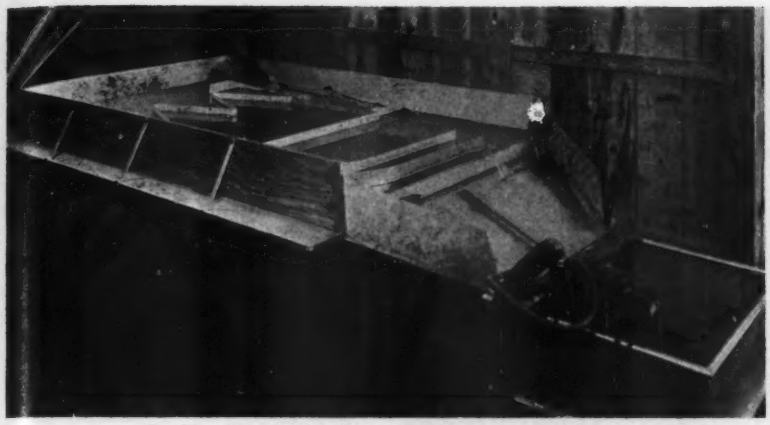

Fig. 11. General view of water model test arrangement.

part of a CMP unit at an eastern power plant before any corrective devices were installed to control the flow. After the model studies for a typical CMP unit were completed and the results applied at this installation, the gas velocity was again surveyed in the commercial unit using Pitot tubes, and the corrected gas velocity distribution plot is shown in Fig. 10. This work was done in 1950. The great improvement is evident from these plots.

Water Model Studies

Following the work already described with large-scale models using air as a test fluid, it became the practice for several years at Western Precipitation to build models of unusual precipitator installations using water as the test fluid. For example, it was decided to build a model of a large precipitator designed in a double deck arrangement with two wings on each deck, each wing consisting of three units of two sections each. This arrangement involved unusual configurations for leading the gas to the inlets of the various units—configurations quite different from the usual configurations investigated with the large-scale models already described. Models in which water flows over or through an open tray, guided by partitions, vanes, screens, etc., are essentially limited to studies in two dimensions only. However, many problems in gas flow in precipitators are essentially two-dimensional and water model studies are quite helpful in these cases. Their use to guide the design of gas distribution devices in precipitators has been widespread in Germany for many years, for example.

Figure 11 is a photograph showing a general view of one of the water model arrangements tested at Western Precipitation. In order to make the motion of the water visible various substances were added to it such as aluminum powder, potassium permanganate, etc. Such additives were satisfactory for visible observation, but not for making photographs of the flow patterns. For photography, the addition of milk, preferably condensed milk, was found to be far more effective than anything else tried. Figure 12, taken with this technique, shows how the water entered the three units of one wing of the double deck precipitator already mentioned, before any corrective devices were installed in the model. Figure 13 shows how the flow pattern was improved by installing corrective devices. The use of such water models is a quick and comparatively easy way to obtain useful data regarding the flow characteristics in a precipitator, as long as it can be reduced to a two-dimensional experiment, or a series of them.

Studies with 1/16th Scale Transparent Models

In recent years it has become the practice at Western Precipitation to build and test $^1/_{16}$th scale transparent models of certain precipitator installations before they are built, especially those jobs which include unusual ductwork and other devices ahead of and following the precipitator. Such models are useful in arriving at an efficient over-all design of the precipitator and associated components in which the total pressure drop required to maintain the desired gas flow rate is reduced to a minimum. For a large modern boiler in a power plant, each inch of water which the fans must furnish for such pressure drop is evaluated at the order of 20 to 40 thousand dollars, considering not only the cost of the fan and motor but also the electrical energy required over the years of lifetime of the plant. Hence if a model study can save $^1/_2$ inch of water in the over-all pressure drop and improve precipitator performance, it is well worth-while, Figure 14 is a photograph of a $^1/_{16}$th scale transparent model of an eastern coal-fired power plant layout which includes the air preheater, the precipitator, the induced draft fan, the stack, and the associated ductwork. Actually, the complete installation included another similar parallel layout alongside this one, but the two were symmetrical, so there was no need to model both of them.

Fig. 12. Pattern obtained with water model for three units of one wing of double deck precipitator before any corrective devices were installed.

Fig. 13. Pattern obtained with water model for three units of one wing of double deck precipitator after corrective devices were installed.

Gas Flow Rate Measured

The gas flow rate through such models may be measured by traverses of the duct with a small Pitot tube, or by use of a calibrated orifice. Although it is possible to measure the differences in static pressure at various points in the model, and to determine whether changes in the ductwork or in the vanes or other gas flow control devices increase or decrease the pressure difference, the corresponding increase or decrease in the pressure drop in the actual unit is not predictable in magnitude from the model studies alone. That is, one cannot measure a pressure difference between two points in the model, multiply this difference by some factor and say that the result will be the corresponding pressure differences in the actual installation, because of the disparity in values of the Reynolds numbers in the model and the actual unit.

A general qualitative impression of the gas flow in various parts of the model can be obtained quickly by introducing titanium tetrachloride smoke at the point of interest through a small tube inserted through a hole in the model. Regions of high gas velocity or low velocity, regions of reverse flow, and the presence of eddies can be quickly and easily seen by this method when the model is properly illuminated with brilliant floodlights.

Quantitative data regarding the gas velocity distribution are obtainable by

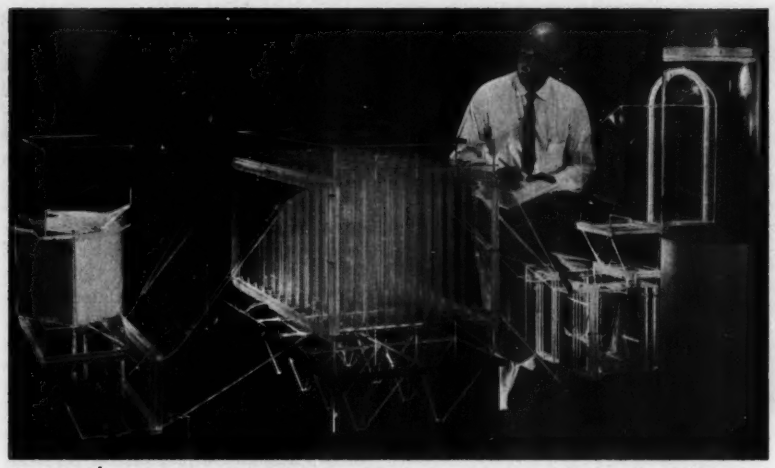

Fig. 14. 1/16 scale transparent model of coal-fired power plant precipitator and associated duct work.

means of hot-wire anemometers now available.† These have small probes, which are highly desirable for work in 1/16th scale models, and are available in directional and non-directional types. As in the work already described with larger models, it is desirable to take the anemometer readings from some large number of evenly distributed points in a transverse plane of the precipitator, say 50 points or 100, for example, and plot them in a diagram resembling Figs. 7 and 8. This should be done in several planes, and for several different arrangements of the gas flow control devices in order to select the best one. Information about the direction of the air flow at any point in the model may be obtained by inserting a small rod with a short piece of flexible thread or string attached to the end of it, placing the end of the rod at the point of interest. If this point of interest happens to be just inside the test hole, say 1/2 inch from it, it is essential that the annulus between the hole and the rod be sealed; otherwise, air rushing in or out through this annulus will lead to completely erroneous data. This applies equally also to velocity measurements with the hot-wire probe.

General Conclusions from the Model Tests to Date

To some extent, each job is a special case having its own peculiarities of gas flow, but there are a few general statements which can be made which have general application to almost any job. The following statements are in this category, and like most general statements, it is usually not very difficult to find exceptions to them.

1 Properly designed turning vanes are very good for preserving a good distribution of the gas velocities as the stream goes around a bend or diverges in one plane; they are equally good for preserving a bad distribution. They are not able to convert a bad distribution into a good one, in general.

2 For improving a poor gas velocity distribution in a gas stream, a device to uniformly restrict the gas stream, such as a perforated plate, is good.[2] In order to be effective, the percentage of open area should be so chosen as to develop a pressure difference of the order of 1/4 or 3/8 inch of water between the two sides of the device when the gas flow rate is normal. This pressure difference tends to equalize the gas flow through all the holes (assuming equal sized holes). It may be necessary to provide a rapper for the plate to prevent dust from clogging some of the holes.

If a perforated plate has A_h square feet of holes in it, and if gas at a temperature of $T°$ Rankine (Fahrenheit plus 460) is flowing through these holes as a result of a pressure difference H (in inches of water), the gas flow rate, V, in cubic feet per minute is given with sufficient accuracy for our purposes by the empirical equation

$$V = 61.5\, A_h \sqrt{HT} \qquad (2)$$

from which

$$H = 0.000265\, V^2/T\, A_h^2 \qquad (3)$$

or

$$A_h = \frac{0.0162\, V}{\sqrt{HT}} \qquad (4)$$

If one arbitrarily takes $H = 1/4$ inch of water, as suggested above, one has

$$A_h = \frac{0.0324\, V}{\sqrt{T}} \qquad (5)$$

Dividing A_h thus calculated by the total area of the plate in square feet, one obtains the percentage of open area required.

When a gas stream strikes a perforated plate in a direction differing from the perpendicular, it tends to be deflected to one side by this plate, somewhat as though the plate were not perforated, as indicated in Fig. 15.

3 An effective device to correct the poor gas velocity distribution in an abruptly diverging transition such as that shown in Fig. 1 is a pyramid made of perforated plates as indicated in Fig. 16. This should be followed by a transverse flat perforated plate as shown in the figure. The base of the pyramid should be located half way between the inlet and the outlet of the transition, and its altitude should be about 1/4 of the width of its base. The apex of the pyramid should point in the direction of gas flow, and the percentage of open area should be designed to introduce a pressure difference of about 1/4 inch of water between the two sides of the pyramid when the gas flow rate is normal. This type of perforated pyramid is also effective in the case where the diverging transition is not symmetrical.

4 When the gas stream arrives at the inlet of a horizontal flow precipitator flowing in a direction at right angles to the axis of the precipitator, or nearly so, one is faced with the problem of reducing the average gas velocity from values of the order of 50 fps in the duct to a

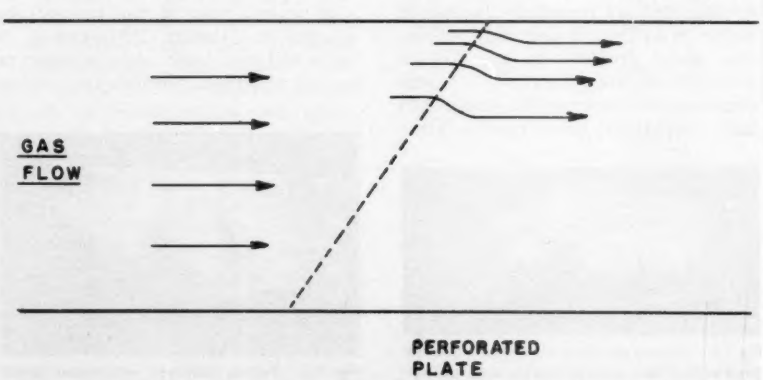

Fig. 15. Sketch showing how a perforated plate deflects a gas stream to one side when incident angle differs from 90°.

† For example, Hastings-Raydist, Inc., Hampton, Virginia.

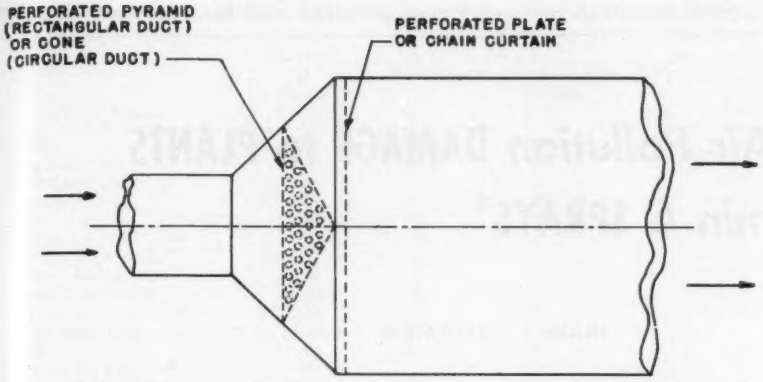

Fig. 16. Sketch showing use of a perforated pyramid to distribute gas stream flowing through abruptly divergin transition.

velocity of the order of 5 fps in the precipitator, and making a right angle bend at the same time. The cross sectional area of the gas stream must therefore increase by a factor around 10. The large-scale model experiments showed that one effective means for correcting the flow in this difficult situation is a device consisting of a combination of perforated half-cylinders and deflectors ahead of the usual perforated plate at the inlet of the precipitator. A typical arrangement is shown in Fig. 17.

5 When the gas stream enters the precipitator from a Multiclone ahead of it, as in a "CMP unit," a combination of deflectors over the lower rows of Multiclone outlet tubes, plus a partly perforated vertical baffle hung from the top of the 90° bend was found to be an effective combination to use in front of the usual flat perforated plate at the precipitator inlet to achieve good gas velocity distribution. Its effectiveness was proved in practice later, as shown in Figs. 9 and 10.

6 The use of one, two, or three vanes or deflectors in a large duct or plenum (say, 20 feet square) to divert the gas stream from one side towards the other is poor practice. Such arrangements are sensitive to changes in the gas flow rate, and may function reasonably well at one rate but not at others. This sensitivity to gas flow rate does not apply to a properly designed set of turning vanes, or to a gas velocity distribution device such as a perforated plate.

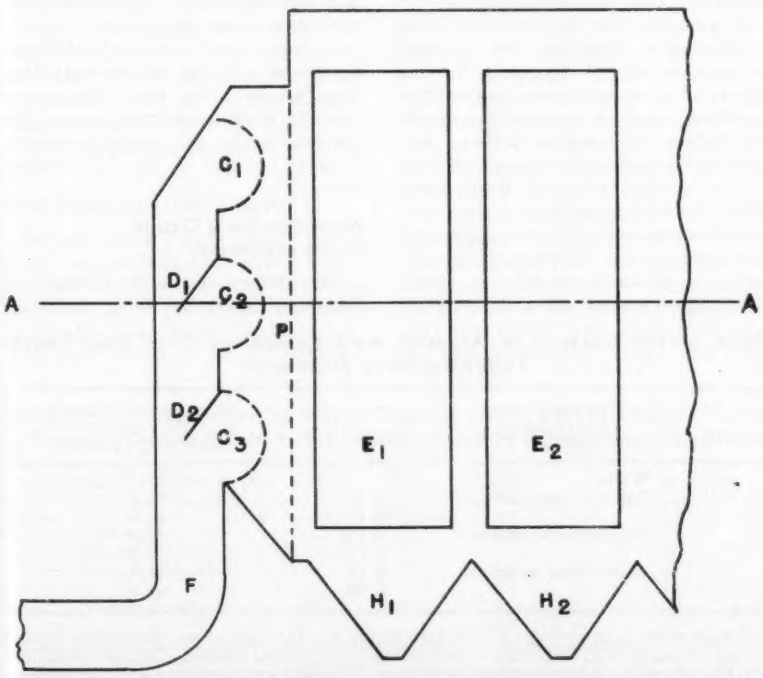

Fig. 17. Arrangement of perforated half-cylinders and deflectors which has been found effective for distributing gas stream arriving at precipitator inlet in direction at right angles to precipitator axis.

7 If a nearly uniform distribution of gas velocities is present at some particular cross section of the inlet duct system ahead of the precipitator, the use of properly designed turning vanes and dividers to preserve this good distribution and to minimize turbulence is very desirable. Besides maintaining good velocity distribution it also reduces the pressure difference across the whole system. In designing such vanes and dividers, one must allow for the presence of dust in considerable concentration and realize that if the usual vane design used in ventilation systems is adopted, there may very probably be some of the vanes which will build up heavy dust deposits that may destroy the effectiveness of the vane arrangement or even clog it entirely.

This group of generalizations will give some idea of the type of information acquired from model studies, but it does not describe the host of detailed results obtained from experiments related to the particular peculiarities of each individual job. Familiarity with these can be acquired only by actual experience in this type of work, and cannot be described effectively in a technical paper of reasonable length.

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Personalia

(*Continued from page 302*)

for the City of Cleveland. He is currently conducting a "Basic Study of Air Pollution Wet-Scrubbers" as the result of a grant from the U. S. Public Health Service, and is involved in assessing more precisely the effectiveness of certain contacting systems used to remove contamination from gases and vapors produced in industrial areas.

* * *

R. F. Protiva has been named Manager of the Cleveland plant of Heil Process Equipment Corp., in charge of all manufacturing, estimating, and product promotion of the company's line of chemical resistant process equipment including lined acid tanks, Nocordal impervious graphite heat exchange equipment, steam jet agitators, and numerous corrosion resistant linings.

Mr. Protiva joined Heil Process Equipment Corp. as Sales Engineer in 1940 following his graduation from Case Institute of Technology with a degree in Metallurgical Engineering. He became Manager of Process Industry Sales in 1956, Eastern Sales Manager in 1957 and Manager of Market Development in 1959.

The PREVENTION of Air Pollution DAMAGE to PLANTS by the USE of Vitamin C SPRAYS*

HUGH T. FREEBAIRN, University of California, Riverside, Calif.

Much concern has been evident in the literature of the past few years about the concentrations of ozone and other oxidizing materials in the polluted air of American cities. These compounds have been suspected of being the irritating agents that are responsible for plant and animal injury and property damage. Concentrations of ozone sufficient for plant damage have been reported in the atmosphere of a number of cities.[4] The results of the work presented in this paper offer additional proof that ozone and possibly similar compounds are involved as smog damaging agents to plants in the Los Angeles Basin.

More than a decade ago ozone was believed to be a beneficial agent. Microbiologists had demonstrated that it was a very active bacteriocidal agent and other workers had found that it was an effective deodorizing agent. Further work revealed, however, that ozone was as toxic for animals and man as it was for bacteria[3, 14] and studies with plants showed that here again it was an extremely active toxic agent.[6]

In the last few years, laboratory results have shown that vitamin C and other reducing agents which naturally occur in living cells have the ability to protect animals,[5, 13] as well as protect the respiratory particles inside plant cells[4] from the damaging effects of ozone. In lieu of this protection in the laboratory against the gaseous oxidizing agent ozone, we considered it important to determine if a similar prevention of damage could be obtained with intact plants out in the field.

Before attempting such a program for treating plants with a natural reducing agent such as vitamin C, it was necessary to discover the proper application which would increase the plant's content of the compound. Since too great a concentration could actually be toxic to plants, it was also necessary to establish the tolerance levels which different plants had for the vitamin C treatments. When these two objectives had been accomplished then it was possible to treat the plants to see if protection from ozone as well as Los Angeles type smog could be obtained.

Increasing the Vitamin C Content of Plants

In the past, a number of workers have applied vitamin C to plants with varying results. Generally two methods had been effective in increasing the vitamin C content of plants, i.e., stem injection[12] and the addition of the salts to the roots of plants growing in water culture.[1] Both of these methods were not practical for the projected field applications. Therefore, the spraying of various salts of vitamin C on the leaves of plants was undertaken and the results of one such analysis[10] are shown in Table I. It can be seen that a significant increase in this vitamin in bean leaves resulted with all three salts. Both the concentration of a given salt and the form of the salt were important in obtaining the increases. The application of similar sprays to seven other plant species was also found to significantly increase the amount of the vitamin inside the leaves.

Tolerance of Plants to Vitamin C Sprays

As stated above, in order to avoid damaging plants from the sprays used in the field, it was necessary to conduct preliminary greenhouse tests to establish tolerance levels. Table II shows the results of these tests. A concentration of 0.1*M* potassium ascorbate caused leaf burning, leaf drop, and retarded growth. Sprays containing 0.01*M* ascorbate did not cause any observable effects even after prolonged treatment of the 19 different plant species tested which indicated that this was probably an acceptable concentration for application. There was some indication that plants grown in the greenhouse were more easily damaged by excess amounts of ascorbate than those grown in the field. Because of this, Table II served only as a guide for establishing the proper concentrations to be used in the field applications.

Protection from Ozone in the Laboratory

The amount of vitamin C inside the leaves of plants can be increased by

Table I—The Increase in Ascorbic Acid Content of Pinto Bean Leaves Following Spray Treatments

Treatment and Concentration (Molar)		Ascorbic Acid Found[a] (% of that Originally Present)
Water		36.2[b]
Calcium ascorbate	0.02	55.5[c]
	0.05	46.0
Potassium ascorbate	0.02	53.8[c]
	0.05	60.3[d]
Ammonium ascorbate	0.02	34.3
	0.05	64.8[d]

[a] Each value is an average of 12 determinations. The leaves were thoroughly washed before the analysis so the values represent the total reduced vitamin C inside the leaves.
[b] This shows the normal increase in vitamin C content irrespective of spray treatment.
[c] Statistically different from the water control at the 0.05 level.
[d] Statistically different from the water control at the 0.01 level.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

Table II—Average Leaf Burn Resulting from Potassium Ascorbate Sprays[a]

Type of Plant	Number of Plants Tested	Concentrations of Spray Solutions (Molar) 1.0	0.5	0.1	0.01
Alfalfa	220	Retarded	0	0	0
Beet, Red Ball	100	6	5	0	0
Carnation flowers	48		8	4	0
Calendula	24		0	0	0
Celery	220	9	8	0	0
Endive	500	9	7	0	0
Grapefruit seedlings	100	2	1	0	0
Lettuce, Burpiena	200	9	7	0	0
Lettuce, Escarolle	200	9	6	2	0
Lettuce, Romaine (cos)	110	7	1	0	0
Orange seedlings	100	4	1	0	0
Orchid[b]	12	Leaf drop	0	0	0
Petunia, La Paloma[b]	48		9	3	0
Pepper, Calif. Wonder	100		Retarded growth	0	0
Pinto bean	108			8	0
Rose, 5 varieties	15		Leaf drop	Leaf drop	0
Snapdragon	28		2	0	0
Spinach[b]	110	9		Retarded growth	0
Swiss chard (Lucillus)	50	5	2	0	0
Tomato (Pearson)	64	9	4	0	0

[a] The burning was rated on a scale of 10. Ten indicated 100% of the leaf surface burned. The results are from a single spray application unless indicated otherwise.
[b] Results from spraying five days per week for three weeks or more.

direct spraying with ascorbate salt and can also be increased by the addition of the salts to the solution surrounding the roots of plants growing in water culture.[1] This latter method was more desirable for laboratory studies since any protection which was obtained had to result from the movement of the vitamin through the root and stem and into the leaf and not from any chemical action between vitamin C and ozone on the surface of the leaf. Table III contains the data from one such experiment. It is to be noted from the table that the pH of the nutrient solution was an important determinate for the movement of the vitamin into the plants as well as for the prevention of leaf damage from ozone fumigations.

Field Protection with Vitamin C

Romaine lettuce and spinach plants grown commercially at Torrance, Calif., were sprayed one, two, and five days per week with potassium ascorbate. The applications were started on May 8, 1958, and the smog attacks occurred on about May 28, 1958. No significant amount of protection was obtained on the spinach plants; 53% of the leaves on the plants were heavily damaged. Table IV shows the results obtained with the romaine lettuce plants.

It was evident that a one day a week application (on Mondays) gave no protection even though high concentrations of ascorbate were used. A 66% protection was obtained, however, with a two-day per week application (Monday and Friday) and an 82% protection with a five-day per week application. Several other instances of protection to romaine lettuce in the Los Angeles Basin have been obtained. In one case complete protection resulted. The data in Table IV also indicate that the ascorbate moved into the leaves when protection was obtained.

Poa annua plants were grown in the greenhouse built by the Air Pollution Control District at the Los Angeles State and County Arboretum in Arcadia, Calif. The growing conditions and the method for determining the per cent of leaf area damage have been described by Juhren et al.[7] One of three groups of plants was sprayed five consecutive days with 0.04*M* potassium ascorbate before being exposed to polluted air. The other two groups were sprayed three consecutive days and one day before exposure with a similar solution. When annual blue grass was sprayed for five consecutive days before being exposed to naturally occurring smog, a 39% protection was obtained. These data, shown in Table V, were the result of a combined effort with Mr. Noble and Marcella Juhren. Applying ascorbate for the three days prior to exposure did not protect the plants. It appears that a certain element of time was involved for the absorption of the vitamin C and if, as in the case with the lettuce tests (shown in Table IV), the ascorbate was applied on alternate days, a higher percentage protection possibly could have been obtained. If this is true, then perhaps a three-day per week application could have given as much protection as a five-day application if the treatments were given on alternate days.

Petunia plants grown under glass at Montebello, Calif., were treated with vitamin C. Four flats were divided in halves and one half of each was treated with sprays and the other with water as shown in Table VI. Three additional flats were watered daily with the solutions shown as soil drench. It was evident that potassium ascorbate was able to give up to 67% protection to the petunia plants. Ascorbic acid, however, burned the plants because of its acidity at the higher concentration. At lower concentrations some leaf burn was also observed with this acid; however, a certain amount of protection was obtained. The vitamin C added to the soil had little or no effect presumably because it was decomposed by the microorganisms which were present.

Eight groups, each containing nine tomato plants, were grown under glass in Rialto, Calif. Four groups received air filtered through activated carbon and the other four received unfiltered air. Each group was sprayed five days per week with one of the solutions being tested. The weight of the fruit obtained from each plant was determined as well as the extent of leaf damage and vitamin C content of the leaves. The treatments were applied regularly over a four-month period.

It appears from the data in Table VII that the carbon filters significantly increased the yield, both in grams and in number of tomato fruit. The 0.001 *M* ascorbate spray significantly increased the number of fruit in the non-filtered house. There was a trend for increasing number of fruit and weight of fruit from the 0.001 *M* ascorbate treatment in both the filtered and non-filtered house;

Table III—The Prevention of Ozone Damage to the Leaves of Bean Plants by Adding Vitamin C Salts to the Nutrient Solution Surrounding their Roots[a]

Compound Added to the Nutrient Solution[b]	pH of the Nutrient Solution	% of Leaf Area Damaged by O_3
None	6.5	32
Potassium chloride	7	29
Potassium succinate	7	22
	5	21
Potassium ascorbate	7	7
	5	30

[a] The plants were fumigated with 7–10 ppm of ozone for 2 hours. Each value is an average obtained from 12 different plants.
[b] The compounds were all at 0.01 molar concentration.

Table IV—The Prevention of Smog Injury to Lettuce Plants by the Application of Potassium Ascorbate[a]

Spray Applied	Frequency of Application (Days/Week)	% of the Leaves Damaged[b]	Average KAA Content (μg/gm F W)
None	—	33	525
0.04 *M* KAA	1	37	560
0.04 *M* KAA	2	11[c]	887[c]
0.02 *M* KAA	5	6[d]	700

[a] Abbreviated KAA. The maximum concentration of oxidants on May 26 and May 28, 1958, reported for Pasadena were above 0.5 ppm.
[b] Each value represents an average obtained from 24 plants.
[c] Statistically different from the water control at the 0.05 level.
[d] Statistically different from the water control at the 0.01 level.

however, for the most part, the variation between plants was too great to make this trend statistically significant. Since ascorbate seemed to have less effect on the plants receiving filtered air than those receiving unfiltered air, there was a possibility that some protection with the sprays was obtained.

There are possibly three complicating factors affecting these results as well as the results of any other similar long-term experiment. If ascorbate caused better nitrogen utilization by the plants, then they in turn would have been more susceptible to the smog poisons, since nitrogen nutrition has been shown to be related to smog susceptibility. On the other hand, ascorbate could also decrease the smog damage by its accumulation in the leaf cells. Ascorbate has also been shown to accelerate growth and productivity of plants, however, the nature of these effects are not truly known and could involve nitrogen metabolism.

It should be mentioned that the 0.05 *M* spray burned a number of the leaves on the plants receiving this concentration. However, none of the other treatments caused leaf burning on any of the plants.

Table V—The Prevention of Air Pollution Injury to Poa Annua by Ascorbate Sprays

Treatment[a]	Average Per Cent Damage[b]
0.02 *M* Potassium ascorbate	
1	29.4
3	33.0
5	18.0[c]

[a] The plants were sprayed 1, 3, or 5 consecutive days before exposure on May 16 and 17, 1958, to naturally occurring smog at Arcadia, Calif. On these days an oxidant concentration above 0.5 was reported at Pasadena, Calif.
[b] Each value is an average from at least 22 separate leaf determinations.
[c] Significantly different from the one day and two day spray applications at the 0.01 level, L.S.D. = 10.

The ascorbic acid content of the leaves of sprayed plants in one instance in each house was significantly greater than those plants receiving no spray applications. This indicated that the ascorbic acid was moving into the leaves and other plant parts.

Table VIII shows the results obtained with roses. The ascorbate treatments caused an increase in stem length and number of flowers at both of the concentrations used. Since heavy smog was not observed during the tests, this is probably a growth effect of the vitamin C on the plants.

Spray applications were made to a number of different varieties of orchids and carnations. In tests involving more than 1800 orchid plants, 63% of the flowers were damaged over a two-month period by the polluted air in the Los Angeles Basin. This damage took place during the latter months of 1957 and represents a considerable loss to the ornamentalists. The vitamin C sprays had no significant effect on the amount of damage to orchids. An increased rate of recovery was observed on carnations following cutting, however, it was difficult to measure quantitatively.

Since concentrations of ethylene of 0.5 ppm[11] have been reported during smog attacks in Pasadena, Calif., and 0.002 ppm of ethylene for 24-hour exposures have been shown to produce orchid damage,[2] it appears that the dry sepal wilt of orchids could be caused by the excessive amounts of ethylene in the polluted air rather than ozone and other oxidants.

Discussion

The evidence presented here indicates fairly conclusively that vitamin C applied as a spray moved into the leaf cells of some plants and because of its presence increased the tolerance of the cells to the damaging agents in smog. The protection afforded by vitamin C in the laboratory from ozone and in the field from air pollutants implied that either ozone was a damaging agent in the field or that vitamin C was effective against other toxic agents in the field. Of course both possibilities could have been occurring together.

It is interesting that in some instances complete protection was obtained, but in most of the cases only partial protection resulted. This could serve as suggestive evidence that more than one group of toxic agents were present in the polluted air and vitamin C was only effective against one particular group of these toxic agents (the oxidants seem to be the most reasonable group for vitamin C action). One would not expect, for instance, that vitamin C would be effective against pollutants such as ethylene.

Another consideration which probably was important was the relationship between the concentration of the toxicants in smog and the amount of vitamin C in the plant cells. High concentrations of toxicants would presumably damage the cells in spite of the presence of increased amounts of the vitamin because the vitamin increases were small in comparison to the increased smog. Different plants absorb vitamin C at widely varying rates and also differ in their susceptibility to smog poisons. This possibly accounts for the fact that spinach was not protected while romaine lettuce was. Both of these plant types grown in the same field, received the same vitamin treatment and were exposed about the same to the polluted air.

Table VI—The Prevention of Smog Damage to Petunias (La Paloma)

Treatment[a]	Total Number of Leaves in Treatment	Number of Damaged Leaves in Treatment	% of Leaves Damaged
1. Control	300	177	59
0.1 *M* potassium ascorbate spray	286	103	36
2. Control	200	141	70
0.01 *M* potassium ascorbate spray	235	54	23
3. Control	415	312	75
0.1 *M* ascorbic acid spray	390	390	100
4. Control	298	173	58
0.01 *M* ascorbic acid spray	269	89	33
5. Water, spreader soil drench	497	349	70
6. 0.01 *M* potassium ascorbate soil drench	547	323	72
7. 0.005 *M* potassium ascorbate soil drench	395	246	62

[a] The plants were treated 5 days per week for a 3-week period at Montebello, Calif.

Table VII—The Results Obtained from Tomato Plants Sprayed with Potassium Ascorbate in the Absence and Presence of Polluted Air

Treatment	Number of Fruit[a]	Average Total Weight of Fruit (gms)	Average Leaf Content of Ascorbic Acid (μg/g F W)
Filtered			
None	22.8	2907	458
0.001 *M*	25.7	3106	
0.01 *M*	20.4	2619	643[b]
0.05 *M*	24.7	2540	607
Not filtered			
None	15.8	1959[d]	620
0.001 *M*	20.6[b, c]	2350	
0.01 *M*	19.1	2282	621[e]
0.05 *M*	17.7[d]	1674[d]	700[b]

[a] Each value is an average obtained from nine separate plants grown over a period of four months.
[b] Statistically different from the nonascorbate treated plants in the same house at the 0.05 level.
[c] Significantly different from filtered control plants at 0.05 level.
[d] Significantly different from filtered control plants at 0.01 level.
[e] Leaves were in poor condition at the time of analysis.

Table VIII—Effect of Ascorbate Sprays on Golden Rapture Roses

Application	Total Number of Flowers	Total Length of Flower Stems (Inches)
None	145	2122
Water	143	2172
0.025 *M* KAA	154	2284
0.05 *M* KAA	172[a]	2596[a]

[a] Significantly different from the water control at the 0.05 level.

Acknowledgments

The author would like to express his appreciation and acknowledgment of the untiring efforts and facilities supplied by Mr. Jack Davidson and Dr. Oliver C. Taylor at the Citrus Experiment Station, Mr. Wilfred Noble and Mrs. Marcella Juhren with the Air Pollution Control District in Los Angeles, Mr. Ito and Sons of Chino, Calif., Perry's Bedding Plant Growers in Montebello, Mr. Yamamoto, and the San Lorenzo Nursery Company of Torrance, Calif., and numerous other growers. Materials and funds were also kindly supplied by Chas. Pfizer & Co., Inc.

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SHOCK WAVE CLEANING of Air Filters*

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Economical air pollution control equipment for dust and fume collection from high temperature gas streams (1000°F, and higher) is required for removal of 90 to 99% of sub-micron particles from metallurgical processes, manufacturing operations, power production, and other combustion sources (i.e., incinerators, gas turbines, etc.). This device should be compact, self contained, and inexpensive with respect to capital and operating costs since these are frequently not offset by value of recovered product in air pollution control applications. Available commercial control equipment requires large capital investment (electrostatic precipitator),[1] or high operating costs (Venturi scrubber),[2] or large space for installation (bag filters).[3] In many cases these collectors require auxiliary gas cooling (to about 500°F) which may also add significantly to the costs and complexity of the total gas cleaning equipment installation. Development of fabric media for bag filters to withstand gas temperatures up to 1000°F is currently centered on lubricant coatings for glass[4] and asbestos[5] fibers to make them more resistant to mechanical flexure while collected dust is removed. These newer treatments appear promising for problems where large space for bag collectors is available. Limitations to fabric treatments lie in the ability of the lubricant itself to withstand the temperature.

Another device used for removing small particles from hot gas streams is the deep-bed filter, composed of fine refractory fibers formed into (1 or 2 in.) beds.[6, 7] We have used mineral or slag wool fiber filters[8] in this application, for filtration of open hearth furnace fume from 1000°F waste gases. First, Graham, et al.[7] have used refractory Fiberfrax (aluminum oxide and silica) fibers to filter high temperature gases from nuclear reactor tests. Fiberfrax is still fairly costly but will resist extended exposure to elevated temperatures (2000°F). Commercial kaolin fibers and potassium titanate fibers are also quite refractory, but relatively high in cost. We have made preliminary studies of the kaolin fibers and find that they are somewhat larger than the slag wool fibers ($<4\mu$).

The slag wool filter has been shown to remove 90 to 99% of sub-micron particles at a filtering velocity of 100 cfm/sq ft. Choice of blast furnace slag wool was dictated by its low cost (1¢/lb) and availability to steel manufacturers as a natural by-product of metallurgical production. It is also widely available as home insulation wool.

As the slag wool filter collects fume, its resistance to gas flow rises at the rate of about 0.2 in. H_2O/min on an inlet loading of 0.1 gr/cu ft. Present operating criteria require a maximum operating resistance for the filter unit of 4 in. H_2O. Clean filter resistance at 100 fpm is of the order of 2 in. H_2O, which means that the filter operates about 10 minutes on the above loading to reach a total resistance of 4 in. H_2O. If the operating resistance criterion is raised to 6 or 8 in. H_2O, length of operation on a filter may be extended to 20 or 30 minutes, respectively.

Past tests on slag wool filters have been conducted for the most part with moving webs carried on perforated belts or sheets to convey clean fiber media into the gas stream as required to keep resistance constant.[7] To minimize auxiliary fiber handling and washing equipment, current developments are concentrated on means of cleaning the wool in place. One novel method to achieve this reduction of resistance has shown considerable merit in laboratory investigations. Collected material is removed from filter fibers by the action of a shock wave passed through the deep bed slag wool filter in a direction opposite to normal air flow, thus entraining deposited fume (increased in particle size, as will be shown) in a small volume of auxiliary air. This restores the clean filter resistance and the entrained material can be settled or removed by auxiliary cyclonic chambers.

A shock wave (or an abrupt high pressure front) originates from the explosive release of a relatively large amount of energy in a limited space.[9] It travels through the surrounding medium with a velocity greater than the speed of sound in the medium, producing local heating, expansion, and rarefaction as the wave passes. Actual mass flow of material in the wave is small and for most low pressure shocks is at relatively low velocity. For example, with 5 in. Hg shock overpressure, velocity of the shock wave itself is about 1100 fps in air, the peak wind velocity is 140 fps (95 mph), and velocity pressure is about 4 in. H_2O. The combination of the rapidly moving shock wave, the slower moving wind, and the effects of transfer of pressure to stationary objects is called blast wave. A blast wave passes through the slag wool filter in a very short time since the filter is 97% voids, and in considering effects the filter may be regarded as a drag-type structure. The degree of blast wave removal of collected particles for a drag-type structure depends upon the length of time the filter is subjected to a positive force (i.e. the length of the positive phase of the shock wave). Larsen[9] has shown that sonic velocities are necessary to remove small particles from fibers, due to large Van der Waals' and surface tension forces.

Since mineral wool fibers are small and fragile, they cannot be subjected to repeated dry handlings although we have obtained seven to nine lives by wet handling. A shock (blast) wave offers a combination of useful factors for cleaning of filters of the high void volume used here; it has low material velocity, wind speeds are low enough so that relatively little force is applied to

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* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

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Table I—Dust Dislodged from Filters by Shock Waves

Test Device[a]	Shock Wave Pressure[b] in. Hg	Initial Dust Load Grams	Initial Dust Load %	Dust Loss Grams-	Dust Loss %	Remarks
A. Laboratory 20 Inch Diameter Shock Tube Study						
Dust-Stop	1.5	—	—	—		Blast effects study—moderate damage[c]
Dust-Stop	3.0	—	—	—		Blast effects study—complete failure
AEC-6	4.3	—	—	—		Blast effects study—no damage
AEC-6	6.3	—	—	—		Blast effects study—partial failure
AEC-6	12.1	—	—	—		Blast effects study—complete failure
AEC-6	3.4	155	75	152	98	
AEC-6	3.7	126	56	74	59	
AEC-6	3.8	26	10	8	32	
AEC-12	5.0	429	100	359	84	
AEC-12	4.7	39	8	20	51	
B. Field Study of Simulated Ventilation System Exposed to Shock Wave from Nuclear Explosion						
AEC-6	2.6	357	98	306	86	
AEC-6	3.2	213	30	155	73	
AEC-6	1.4	275	100	177	64	
AEC-6	1.3	212	25	110	52	
AEC-12	2.8	744	100	557	75	
AEC-12	2.4	575	31	331	58	
AEC-12	3.0	554	56	294	53	
AEC-12	1.1	826	69	460	56	
AEC-12	1.3	585	50	26	4	Filter preceded by blast attenuation device.
AEC-12	1.3	548	49	224	41	

[a] Dust-Stop Fiberglas filter—20 × 20 × 2 inch—800 cfm rated capacity.
AEC-6: Pleated cellulose asbestos paper filter—24 × 24 × 6 inch—500 cfm rated capacity.
AEC-12: Same as above, 12 inches deep—1000 cfm rated capacity.
[b] Peak over-pressure; positive phase duration 800 millisec in laboratory study, and 800 to 1000 millisec in field study.
[c] Extensive reentrainment of dust initially on filter, but not quantitated.

the fibers; and the velocity of the pressure wave is at or above sonic, needed to dislodge collected particles. Results of shock wave cleaning of air filters are presented below.

Results of Previous Investigations

Prior to the start of the present study in the laboratory, a comprehensive investigation had been undertaken for the U. S. Atomic Energy Commission on the effects of shock waves on gas cleaning equipment, particularly filters and electrostatic precipitator plates. This AEC study was composed of two parts: (*a*) an investigation of filter damage and dust reentrainment from commercial Dust-stop and AEC High Efficiency (Absolute) Space Filters held in a 20-inch diameter laboratory shock tube,[10] and (*b*) an extended investigation of dust dislodged from six and 12 in. deep AEC absolute filters and electrostatic precipitator plates (coated and uncoated) in a ventilation system subjected to a shock wave from a detonated nuclear weapon.[11] (Shock waves were produced in the laboratory tube by bursting calibrated Kraft paper diaphragms.) Both of these studies have been reported in detail in references cited, so only a partial summary of pertinent test results is presented in Table I. Laboratory shock tube tests on standard Dust-Stop filters and 6 in. deep AEC filters (24 x 24 x 6 in.) indicated some structural failure occurred at overpressures of 1.5 and 6.0 in. Hg, respectively. Moderate damage or partial failure consisted primarily of movement of filter media within the filter frame, usually $^1/_4$ in. or more away from the blast direction.

Dust reentrainment studies from six and 12 in. deep AEC filters in laboratory and field installations indicate from 4 to 98% of initial dust loading is removed by weak shock waves, at overpressures ranging from 1.1 to 5.0 in. Hg. Dust removal ($\%L$) from AEC filters tested in the field was found to be proportional to overpressure, initial dust loading, and inversely proportional to filter depth:

$$\%L = 126\ L_i\ P^{0.4}/D^{0.8} \qquad (1)$$

where the overpressure (P) is expressed in psi, the initial filter loading (Li) in grams/sq ft of filter surface (100 sq ft for 500 cfm filter, 200 sq ft for 1000 cmf filter) and depth (D) in inches (six or 12). The amount of dust removed from these filters was directly proportional to the amount of dust on the filter before the blast, i.e., a filter with 100% dust load (defined as amount required to double the initial filter resistance) lost essentially all of this dust when exposed to a shock wave. It was found experimentally that peak overpressure was a somewhat less important factor than had originally been suspected, i.e., a doubling of the overpressure with a constant amount of dust on the filter caused only a 30% increase in dust removal.

The purpose of these laboratory and field tests was to establish levels of shock wave overpressures that caused structural damage to elements of gas cleaning systems, particularly filters; to determine amount of dust reentrained from gas cleaning devices below critical (damage) pressures; and to determine effective means of controlling or minimizing both. The rather large amounts of dust removed by shock waves below damage level overpressures suggested this method as a potential means of cleaning filters for reuse. This has led to the application of shock wave treat-

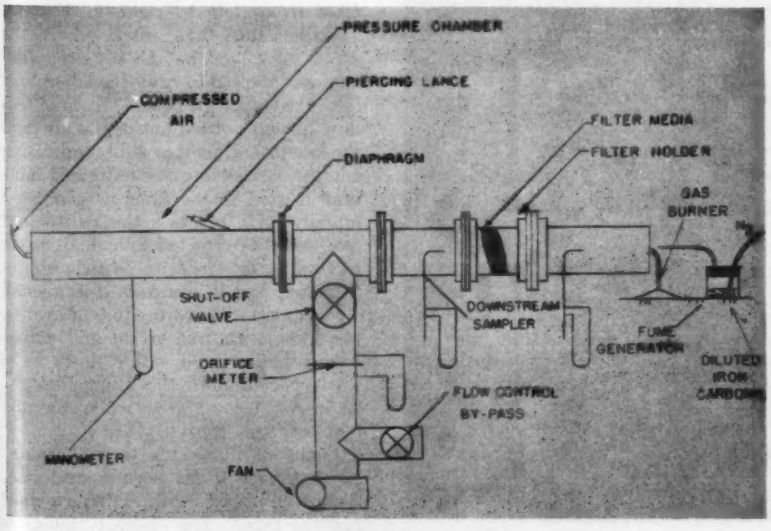

Fig. 1. Laboratory shock tube for slag wool filter cleaning tests.

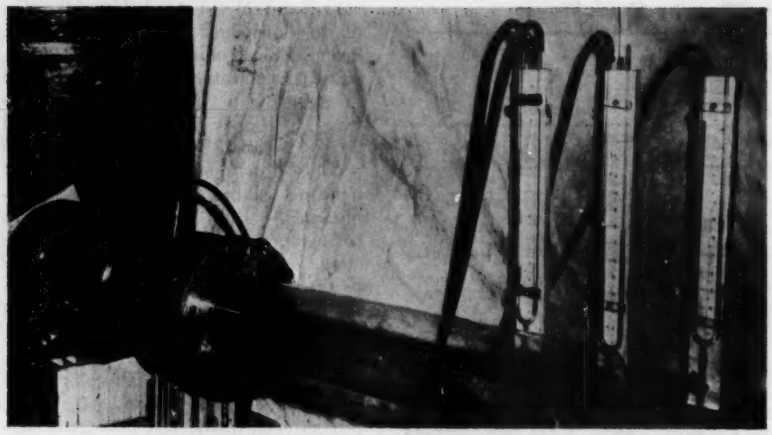

Fig. 2. Shock wave cleaning apparatus (before blast).

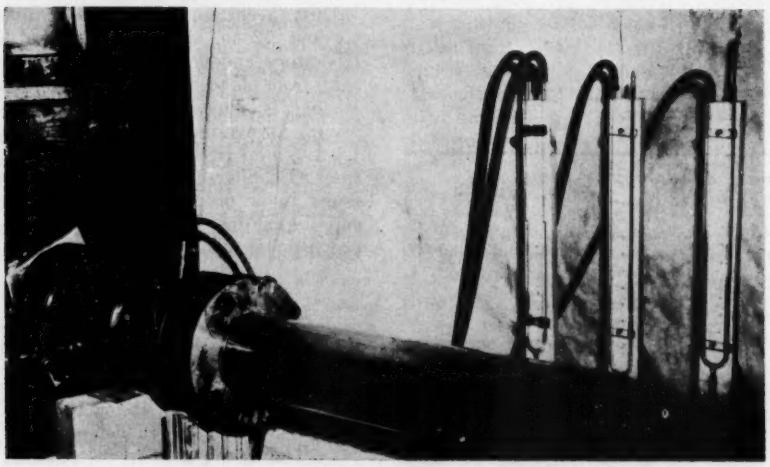

Fig. 3. Shock wave cleaning apparatus (during blast.)

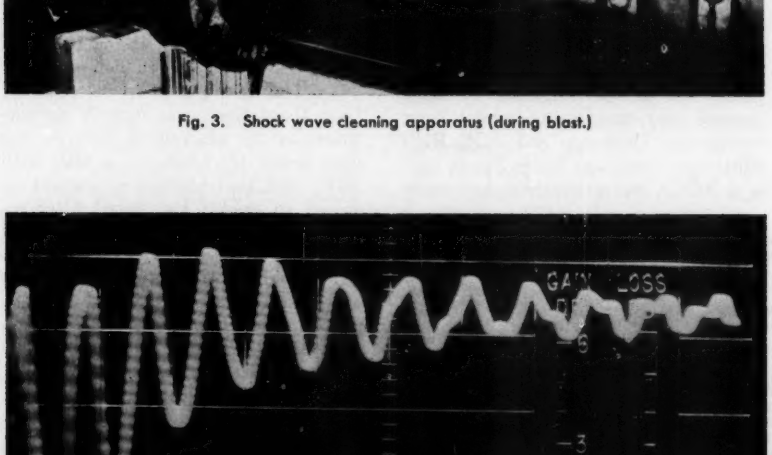

Fig. 4. Pressure wave from burst paper diaphragm during shock wave filter cleaning test.

ment to mineral wool filters used to collect open hearth fume, to lower their resistance periodically during use as described below.

Description and Operation of Test Equipment

To test the effectiveness of shock waves for cleaning of mineral wool filters, our standard 6 in. diameter filter test unit[12] was modified by addition of a 6 in. diameter by 6 ft long (1.22 cu ft) and the blower used to draw air through the system was connected to a tee, as shown in Fig. 1. During normal operation, room air (30 cfm for 150 fpm filtering velocity) was drawn into the 6 in. diameter pipe, entraining iron oxide fume generated by combustion of iron pentacarbonyl ($Fe(CO)_5$) at the inlet. Fume-laden air passed to the 6 in. diameter by 2 in. thick slag wool filter (from right to left in Fig. 1) where fume was removed at 90 to 99% efficiency. The cleaned air was then exhausted through an orifice meter in the branch line to a fan. Up- and downstream samples (1 cfm) were withdrawn simultaneously at locations indicated, by means of sampling probes holding $1^9/_{16}$ in. diameter all glass filter papers. As fume accumulated on the slag wool filter, resistance rose to a predetermined level, whereupon generation of the aerosol was stopped, and the valve on the branch leading to the fan was closed. A Kraft paper diaphragm (one or more sheets, as required) between the pressure reservoir and the filter was then burst by admitting compressed air to the reservoir (to the desired overpressure, usually 5 to 10 in. Hg) and puncturing with the lance shown. This simple process caused a minor explosion which generated a shock wave that traveled down the tube through the slag wool filter (from left to right in Fig. 1). Collected dust was entrained in the shock wave, and for the tests reported here was allowed to enter the laboratory from the end of the tube. Much of this dust quickly settled out of the air onto the laboratory floor, possibly indicating a larger particle size of reentrained fume than existed in the fume as generated initially. (In practice, this redispersed dust could be directed to a small auxiliary collector, since its particle size is increased and it is entrained in a small air volume.) This procedure of loading the filter with iron oxide and subsequently removing it with a shock wave was repeated until the filter efficiency decreased below 80%, when the experiment was stopped.

Figure 2 illustrates the laboratory shock tube with its normal steel inlet section replaced with a transparent plastic tube. The loaded filter is visible at the left end of the plastic

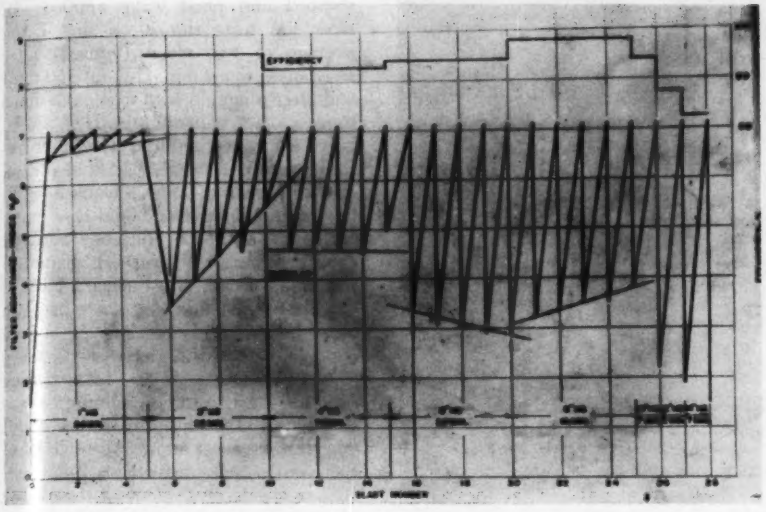

Fig. 5. Effect of overpressure on filter cleaning by shock waves.

tube, and the downstream sampling probe is shown just behind the filter test section (normal air flow is from right to left). Manometers show important pressures recorded during tests; the left-hand manometer indicates the orifice differential (in small branch line, behind screen), metering flow through the filter during filtration. There is a reading of about 8 in. H_2O in this photograph, which represents 150 fpm filtering velocity. The manometer in the center (containing mercury) measures positive pressure in the reservoir behind the paper diaphragm before puncturing (the edge of the paper diaphragm and the piercing pin can be seen at left). During normal air flow the reservoir pressure is zero as shown. Air flow resistance across the filter is measured by the right-hand manometer, and in this case it is measured to atmosphere (only the downstream static pressure is measured). Indicated pressure loss across the loaded filter in this figure is about 7 in. H_2O at 150 fpm filtering velocity.

Figure 3 is a photograph taken just as the photographer heard the blast, and dispersed fume can be readily seen following the blast wave, and settling in the transparent duct. The manometer on the left (in Fig. 3) indicates zero flow through the orifice to the fan (i.e., normal air flow was stopped during several blast tests). The center manometer is indicating a high pressure (10 in. Hg) in the shock wave during the blast, and the manometer on the right is in the process of "blowing" or losing its fluid due to the momentary surge of high pressure as the wave passes through the filter and down the transparent duct during the blast. An oscilloscope tracing of the action of the blast in the tube is shown in Fig. 4, taken by means of a pressure transducer located in the wall of the duct between the blast diaphragm and the downstream face of the filter. Peak blast pressure (side-on) from this tracing is 2.9 in. Hg and positive phase duration is approximately 20 msec. for the first "spike." There are a series of lower pressure pips evident, probably caused by reflections of waves from either end of the blast system, but their importance to the filter cleaning method is not known at this time. This positive phase duration is short in comparison to previous laboratory and field tests (c.f. Table I, footnote *b*).

As part of the study on filter cleaning, changes in physical dimensions in the blast system were made. The reservoir was provided with internal tubes of 4 and 5 in. diameter to reduce the volume to 0.72 and 0.44 cu ft, respectively; and the diaphragm was reduced from the full diameter of the tube (6 in.) to 2.3 in., by means of two flat aluminum plates with $2^5/_{16}$ in. holes that could be gripped between the flanges to restrict the blast diaphragm diameter. In addition, one test was conducted with a scale-up of approximately three to one (diameter), an 18 in. diameter filter holder being made to connect to the 6 in. diameter pressure reservoir (with 6 in. diaphragm). Filters for all tests (including the 18 in.) were made from water slurries (1%) of slag wool mixed by compressed air in a vertical tube of the appropriate diameter; by draining the water out of the bottom of the tube, allowing the wool to be retained on an expanded metal screen at the bottom; and then drying this mat on an electric plate.

Laboratory Test Results

A series of 27 tests were made with the laboratory shock tube, to study effects of changes in shock wave overpressure, diaphragm-tube area ratio, reservoir volume, and filter packing density, as related to degree of cleaning achieved and removal efficiency. The shock tube and pressure reservoir were constructed to permit a reasonable range of test variables to be explored, and the following tests were made: (1) to investigate all important parameters

Table II—Summary of Shock Wave Cleaning Tests on Mineral Wool Filters[a] After Collection of Iron Oxide Fume

Total Tested[b]	Shock Tube Characteristics[c] Dia/R	V/B	P	Inlet Conc gr/cu ft	Filter[d] Packing Density	Filter Resistance In. H_2O[e] First	Init. Avg	Fin Avg	Avg[f] Eff %	Total[g] Number Bursts	Time Min	% Wt Loss
2	6	1.2	5	0.12	5	4.0	4.2	8.0	92	31	69	17
5	2.3	1.2	10	0.06	5	3.8	4.7	8.1	86	42	128	12
1	18[h]–6	1.2	10	0.01	5	2.6	3.3	4.0	81	13	188	—
2	6	0.7	5	0.03	5	3.6	4.8	8.2	90	32	89	8
1	2.3	0.7	10	0.06	5	3.6	4.1	7.9	91	10	16	9
3	6	0.4	5	0.07	5	3.3	5.2	7.5	90	29	59	3
4	6	1.2	8	0.05	3	2.1	2.3	5.5	77	13	88	12
1	6	1.2	5	0.02	7.5	7.5	9.0	14.1	99	13	44	—
1	6	1.2	5	0.02	10	9.4	14.7	28.2	99	13	84	0

[a] Bethlehem Mineral Wool—2 in. thick by 6 in. diameter (except in line 3, 18 in. diameter).
[b] Number of filters used in total series of tests.
[c] Dia = diameter of burst paper diaphragm, inches; RV = reservoir volume, cu ft; BP = blast overpressure, in. Hg.
[d] Filter packing density—pounds per cu ft.
[e] At 150 fpm filtering velocity, avg initial does not include "first" value.
[f] Average weight efficiency in all tests including last one of each series which was less than 80%, the criterion for stopping test.
[g] Total number of exposures to blast of all filters tested.
[h] 18 in. diameter (2 in.—5 lb/cu ft) filter mounted on 6 in. reservoir.

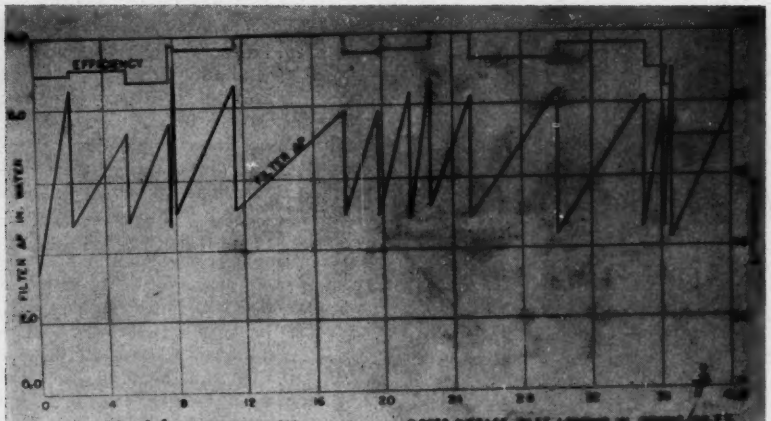

Fig. 6. Shock wave filter cleaning performance curve.

and (2) to permit scale-up design factors to be obtained for a subsequent pilot plant study.

Effects of Shock Wave Overpressure

From previous investigations[6] it had been determined that optimum removal of iron fume with minimal operating resistance could be obtained with 2 in. thick—5 lb/cu ft packing density slag wool filters, and it appeared from studies discussed above that a reasonable shock wave pressure for effective cleaning would probably be within the range of 1 to 16" Hg. Three "standard" (2 in.—5 lb/cu ft) filters were tested by loading them to constant resistance with iron pentacarbonyl generated iron oxide fume, and blast wave cleaning them at successively higher pressures, (with maximum diaphragm diameter reservoir volume). One of these tests is illustrated in Fig. 5. Five successive blasts at 1 in. Hg blast wave overpressure produced very little cleaning, as indicated by the gradually increasing final (after blast) filter resistance. Upon changing to 3 in. Hg (for five blasts) the rate of increase was decreased somewhat, and at pressures of 4, 6, and 8 in. Hg the final resistance was more or less maintained constant. When higher pressures were used (10, 12, 14 in. Hg, one blast each) the final resistance decreased to the initial clean value at the start of the test. Filter efficiency varies somewhat from test to test, but on the average is greater than 90% for the total test. Filter weight loss was 2% of initial weight.

Decrease in filter resistance (ΔR, inches water) was plotted as a function of blast overpressure (P, inches Hg) and it was found that "effect" was a function of the cube root of the overpressure, as predicted by shock wave theory (c.f. 103, ref. 8, where shock phenomena vary as the cube root of weapon yield). The actual operating equation for the 6 in. tube (with 6 in. diameter, 2 in. thickness, 5 lb/c.f. filter) is:

$$\Delta R = 2.1\ (P)^{1/3} \qquad (2)$$

between the limits of 3 and 16 in. Hg. Pressures below 3 in. Hg (one and two) caused decreases in filter resistance (ΔR) lower than predicted (approximately 0.4 at 1 in. Hg and 1.5 at 2 in. Hg) because the overpressure was not sufficient to cause a clean, sharp break in the diaphragm, with a certain amount of "bleed-out" of pressure. (There was also a wide range of ΔR values associated with 3 in. Hg, from 1.7 to 4.2 in. H_2O.) This equation checks the finding previously cited[11] where the pressure exponent was 0.4, based on a narrower range of pressures, and fewer tests (Equation 1).

Filter Life

Two standard slag wool filters were tested with the full reservoir volume (1.2 c.f.) and maximum diaphragm diameter (6 in.) until their efficiency after blast was decreased to below 80%. Table II summarizes these tests in line 1. Column 3 shows the average inlet loading to the filters during tests, 0.12 gr/cu ft (0.07 average in the first test and 0.20 in the second). Filter packing density given in column 4 was also varied in later tests for 6 in. diameter, 2 in. thick filters. Operating filter resistance at 150 fpm is given in column 5, the first value listed being the initial clean resistance at the start of testing, before any fume had been admitted; the second and third values listed being respectively the average resistance to which the filter was cleaned by the action of the blast and the average "dirty" resistance at which loading was stopped and blast wave applied. In filter life tests shown on line 1 the average of two clean (unused) filter resistances was 4.0 in. H_2O (at 150 fpm) and after plugging with iron oxide fume to an average value of 8 in. H_2O, a 5 in. Hg blast wave reduced the filter resistance to 4.1 in. H_2O (ΔR of 3.8 in. H_2O) on the average. Equation (2) predicts a ΔR value of 3.6 in. H_2O.

Average filtration efficiency (column 6) on iron oxide fume (0.5 μ diameter) was 92% (95 and 90) during a total of 31 blasts (column 7) on the two filters (20 on the first and 11 on the second) before the decrease to 80% efficiency was observed. Total testing time for the two filters (column 8) was 69 minutes (41 and 28 min, respectively) and the filters lost an average of 17% of their initial weight (column 9)(23 and 12%, respectively). One of these filter life tests is shown graphically in Fig. 6.

It was demonstrated that fiber filters could be restored to their initial (approx.) resistance after filtration of a fine fume for periods of 10 to 20 exposures to a low pressure shock wave (5 in. Hg), without seriously reducing their efficiency. Further studies were then made to investigate effects of shock tube and filter variables.

Effect of Diaphragm Diameter

After investigating pressure and filter life effects with a 6 in. diameter diaphragm, a reduction in diaphragm area of seven to one (from 28.2 sq in.) was achieved with two plates containing 2.3 in. holes centrally located at the opening of the reservoir. Kraft paper was slipped between the two plates and perforated with the piercing lance as previously, but the shock wave was generated from an area of 4.2 sq in.

The second line of Table II presents a summary of test results on five standard filters tested with 2.3 in. diaphragm and 1.2 cu ft reservoir volume. It was found after one or two blasts on the first filter that 5 in. Hg overpressure was not sufficient to reduce filter resistance appreciably (ΔR = 0.7 in. H_2O), so further tests with the 2.3 in. diaphragm were made using 10 in. Hg overpressure. Filter resistance reduction with 2.3/1.2/10 shock tube characteristics was 3.4 in. H_2O (range in five tests 3.1 to 3.6). Average filtering efficiency was 86% (range of the average was 78 to 90%). The five filters tested withstood a total of 42 blasts (from five to 12 per filter) over a total time of 128 min; the average weight loss being 12% for the group. It was evident from this series that a smaller filter/diaphragm diameter ratio required a higher overpressure to achieve results that were comparable to those obtained when the filter and diaphragm were of the same size. Although we did not check the variation of overpressure and degree of cleaning,

it can be assumed that the cube root scaling law obtains, so that performance with the seven to one area ratio is probably reasonably predicted by:

$$\Delta R = 1.5\ (P)^{1/3} \qquad (3)$$

Based on Equation 3, a blast overpressure of 5 in. Hg should give a filter resistance reduction of 2.6 in. H_2O, whereas, it was actually found that 5 in. Hg gave less than 1 in. H_2O. This discrepancy may be due to the limited information taken at 5 in. Hg, or to the poor rupture characteristic of the diaphragm paper.

One other test was run with a nine to one filter/diaphragm area ratio by using an 18 in. diameter filter and the full diameter of the diaphragm (6 in.). Suitable sheet metal transitions were made to adapt the blast reservoir to an 18 in. filter test set-up. Due to restricted fan capacity, it was not possible to raise filter resistance above about 4.0 in. H_2O (c.f. line 3, Table II). It was again found necessary to use 10 in. Hg blasts to achieve reasonable cleaning (5 in. Hg gave ΔR = 0.2). With 18-6/1.2/10 shock tube characteristics, ΔR was 0.7 in. H_2O. Average efficiency was 81% (range in this one test was 70 to 97%) during 13 blasts over a total operating time of 188 minutes. This test again demonstrated the need for higher overpressure when filter and diaphragm were of different sizes, and was used as a basis for scaling up laboratory tests to a pilot plant unit. (Preliminary results of pilot plant studies are given below.)

Effect of Reservoir Volume

To investigate the effect of reservoir volume of degree on cleaning, the reservoir was reduced (from 1.2 cu ft) to 0.7 cu ft by insertion of a 4 in. diameter sealed cylinder, and to 0.4 cu ft by means of a 5 in. cylinder. Diaphragm diameter was first kept at 6 in. for two tests with the 0.7 volume (line 4, Table II) and then reduced to 2.3 in. (line 5), the respective overpressures of 5 in. and 10 in. Hg being used with these diaphragms. Filter resistance was reduced 3.4 in. H_2O with the 6/0.7/5 tube and 3.8 in. H_2O with 2.3/0.7/10 tube characteristics. It appeared that a reservoir volume of 0.7 cu ft (58%) was quite adequate to clean filters when compared to the full (1.2 cu ft) reservoir, ΔR values being essentially the same in each case. Efficiency was not appreciably different, being 90% or better on the average, for total numbers of blasts ranging from 10 to 15. The 6 in. diameter diaphragm with the lower pressure, in two tests of 15 and 17 blasts produced a slightly lower filter weight loss, when compared to the 2.3 in. diaphragm at 10 in. Hg which operated for only 10 blasts before efficiency was re-

Table III—Particle Size of Iron Oxide Fume Removed from Mineral Wool Filters by Shock Wave Cleaning

Test No.	Particle Size—Microns[a] Mg	σg	Mg′	Magnification	Blast Pressure In. Hg
1	0.056	1.9	0.19	30,700	[b]
2	0.12	2.1	0.62	30,700	3
2′	0.32	1.7	0.72	7,700	3
3	0.076	1.9	0.27	30,700	4
4	0.37	2.1	2.0	7,700	6
5	0.063	2.0	0.29	30,700	12

[a] Mg = count median diameter, microns; σg = standard geometric deviation; Mg′ = mass median diameter, microns.
[b] Initial fume size as generated and filtered.

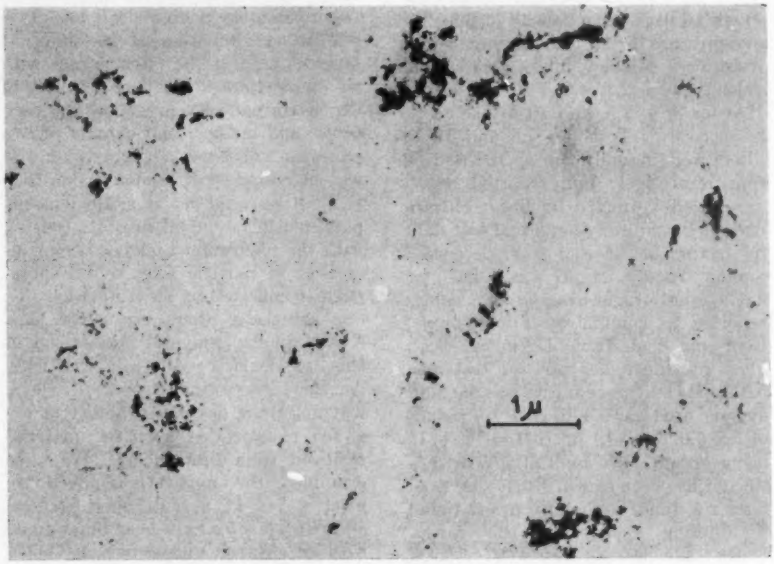

Fig. 7. Initial iron oxide fume as introduced to slag wool filter unit. ×30,000.

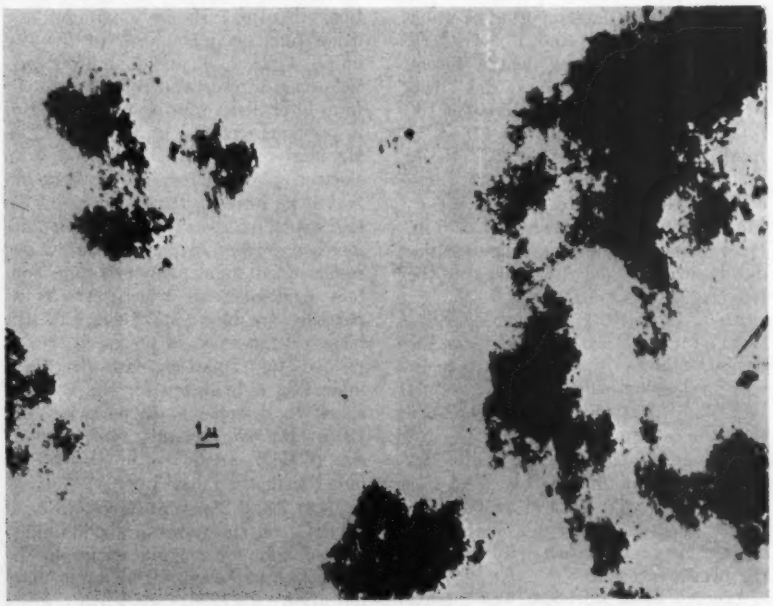

Fig. 8. Agglomerated fume removed by 6-in. Hg shock wave from slag wool filter. ×7700.

duced to less than 80% (criteria for stopping test) with a slightly higher weight loss.

Three filters were tested with 0.4 cu ft reservoir volume, 6 in. diaphragm at 5 in. Hg, yielding an average ΔR of 2.3 in. H_2O. From this we concluded that the reservoir volume was probably too small, or that 5 in. diameter cylinder in the 6 in. pipe restricted formation of an adequate shock wave for filter cleaning.

Effect of Filter Packing Density

Filter packing densities of 5, 7.5, and 10 lb. per cu ft were tested with 6/1.2/5 tube characteristics (lines 1, 8, and 9, Table II) and four tests were made (line 7) with 3 lb packing density at 8 in. Hg overpressure (6/1.2/8). Average initial resistances of these filters at 150 fpm velocity were 2.1, 4.0, 7.5, and 9.4 in. H_2O for 3, 4, 7.5, and 10 lb per cu ft, respectively. Tests on 7.5 and 10 lb filters were actually run at 100 and 50 fpm respectively and reported resistances were corrected by linear extrapolation by multiplying actual test data by factors of 1.5 and 3, respectively. Similar extrapolation was used for average initial and average final values reported in column 5. For example, from line 8 of Table II, initial clean filter resistance at start of test was 5.0 in. H_2O, average initial was 6.0, and average final was 9.4 in. H_2O; the values of 7.5, 9.0, and 14.1 in. H_2O in Table II being obtained by multiplying by 1.5, since it has been shown[12] that slag wool filter resistance is directly proportional to filtering velocity in this range. Shock wave cleaning tests were actually run on the higher packing densities at filter resistances of the same order of magnitude as on lower packing densities because of the lower velocities. The ΔR values from data reported in Table II are 2.3, 3.8, 5.1, and 13.5 for 3, 5, 7.5, and 10 lb packing density filters. Actual values obtained during tests were 2.3, 3.8, 3.4 (from 9.4 to 6.0 at 100 fpm), and 4.5 (from 9.4 to 4.9 at 50 fpm). Fume removal was actually accomplished with 5 in. Hg shock waves at about the same filter resistance (i.e., from 8 or 9 in. H_2O down to 4 or 5 in. H_2O), and higher filter packing densities did not appear to be detrimental to the removal process.

At 7.5 and 10 lb packing densities there seemed to be a tendency for the "average initial" filter resistance to be higher than the "first" clean value. With 5 lb/cu ft filters this difference (between average operating clean resistance and the initial clean value) was 0.2 in. H_2O, but this was 1.0 at 7.5 and 1.5 at 10 lb/cu ft, indicating that the higher density filters were probably not being cleaned as effectively by the 5 in. Hg blast.

Average filter efficiency was related to filter packing density, ranging from 77% at 3 lb/cu ft to 99% at the higher densities (7.5 and 10). In the latter two cases, one filter each was tested 13 times, and the efficiency remained constant at 99% (the 80% efficiency criteria for stopping tests was not achieved at the 13th test).

Agglomeration of Resuspended Iron Oxide

As iron oxide particles accumulate on filter fibers they probably begin to contract already deposited particles fairly soon after filtration has begun. In the case of the slag wool filters used in the foregoing tests, the increase in resistance (approximately double clean values) is due to accumulation of a significant layer at or near the filter surface with the implication that a large number of deposited particles are touching each other, and further, that contact of two particles will cause agglomeration. It was suggested by E. Anderson[13] in 1934 that filters could act as agglomerators, particularly for liquid droplets (mists), with the re-entrained material being increased in particle size, to be subsequently collected by other devices. To our knowledge there has never been shown an experimental verification of this, particularly with solid particles. Another interesting aspect of shock wave cleaning lies in the ability to examine resuspended air-borne material removed from filter fibers. We have examined the particles removed by blast waves at various overpressures, and particle sizes have been determined with an electron microscope, as shown in Table III.

Initial fume particle size is given in test 1, the count median diameter (Mg) being 0.056 μ at 30, 700 × magnification. Figure 7 shows the initial iron oxide fume as introduced to the test unit. Tests 2, 3, and 5 indicate particle sizes of resuspended fume removed from filter fibers (during tests discussed in previous sections) at 3, 4, and 12 in. Hg blast overpressure. Figure 8 is an electron photomicrograph of fume removed by the 6 in. Hg shock wave from slag wool filter fibers. There is a definite increase evident in particle size of the resuspended fume, demonstrating contact agglomeration which persists as particles are blown off fibers. As the blast overpressure is increased, resuspended fume particle size decreases, indicating a tendency for the stronger shock to deagglomerate particles. At 12 in. Hg overpressure, fume particle size (CMD) is 0.063 μ, or about 12% larger than the initial fume.

Tests 2 and 2′ permit a comparison of particles on the same grid determined at two different magnifications on the electron microscope. The lower magnification (×7700) evidently overestimates the fume particle size by a factor about the same as the ratio of magnifications. These studies have shown that a filter acts as a particle agglomerator, and agglomerated material can be removed (and concentrated in a very small air volume) by means of a simple shock wave.

Pilot Plant Field Test Results

We have presented requirements of high temperature gas cleaning equipment for collection of open hearth furnace fume[12] and experience on pilot plant units designed to utilize slag wool fiber as high temperature filter media.[14] Recent developments have been directed toward perfecting the use of slag wool filters in a unit which will provide high efficiency (without mechanical seals), low cost, and minimum space requirements. We are currently testing slag wool filter pilot plant 4 with provisions for several modifications to achieve filter cleaning while the slag wool remains in the filter chamber, as contrasted to cleaning method used on two previous units where the wool was removed from filter and cleaned in auxiliary equipment. The current pilot plant development programs have been summarized recently.[15]

Pilot plant 4 incorporates provision for several methods of filter cleaning to be investigated under field conditions, all designed to minimize fiber handling. One of the methods consists of shock wave cleaning of the filter while it is held in the gas stream, and preliminary test results of this investigation only are presented below. The filter unit, designed for 1600 cfm and shown in Fig. 9, consists of a 5 ft diameter cylindrical plenum 7 ft high with a conical bottom and with a flat top containing a blast pressure reservoir (110 gal. chem. drum) connected to the main chamber by a 24 in. opening for the blast diaphragm. A 5 ft disk to hold the filter is mounted in the main chamber (as shown) on an axle so that it may be rotated (pivotally) upside down to dump the spent filter. A second disk (both contain expanded metal screens to restrain the filter) is mounted on vertical traverse rods and can be lowered from the top, down onto the filter held on the lower screen. Actual internal area exposed to gas flow is 15.8 sq ft.

Figure 10 is a schematic representation of the operation of pilot plant 4C (blast). Slag wool and water slurry are admitted to the unit (top screen has been raised) and mixed by compressed air, the water is withdrawn from the bottom (and returned to a holding tank), the top screen is lowered, the filter is dewatered and dried, furnace gas containing fume is admitted from below, and filtration takes place until the desired maximum resistance has been obtained. A paper diaphragm is placed between the pressure reservoir and the filter chamber,

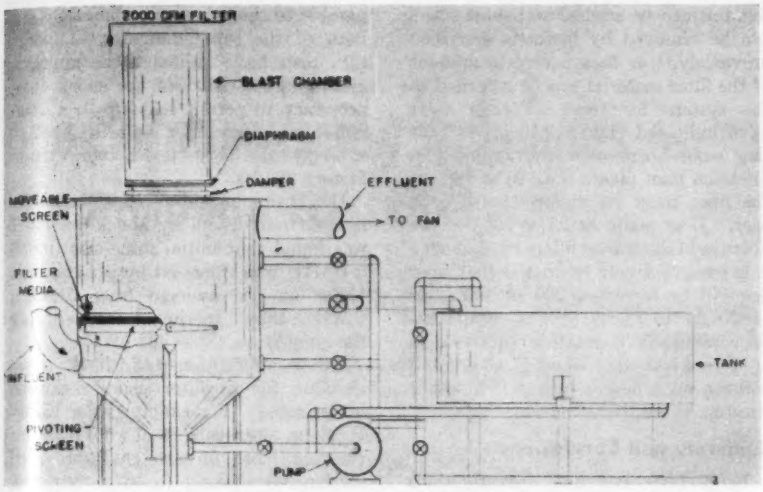

Fig. 9. Open hearth furnace fume filter pilot plant 4.

pressure is raised to 5 in. Hg from plant compressed air lines, a mechanical lance perforates the diaphragm, and a shock wave is generated which passes through the filter to clean it. These latter steps were repeated until filter efficiency is decreased to below 80%, when the top screen is raised, filter is dumped and flushed out of the chamber, new slurry is admitted, and the whole procedure repeats.

Figure 11 is a photograph of the pilot plant filter unit installed adjacent to a 13-ton electric furnace for tests in the vicinity of Boston (no open hearth furnaces being locally available). An inlet line leads from the furnace exhaust stack to the pilot unit, and can be seen coming out the window on the left. It enters the filter unit below the filter, and leaves above (behind) to pass to the gasoline engine driven fan on the left. The blast reservoir (15 cu ft) is located above the unit and a two-ton scissors jack can be seen on the superstructure which forces the reservoir down onto the 24 in. diameter diaphragm location. Inlet sampling apparatus is located at left center of the photograph. Figure 12 shows the 700 gal slurry storage tank (right foreground), 350 gpm slurry pump (left background), and sampling pumps, and filter resistance manometers, etc. for measurement of the operating variables.

Test data are presented in Table IV. Four separate filters were tested, the first two blasts, the second for four blasts, the third for three blasts, and the fourth for 14 consecutive blasts. Filter removal efficiency in the first tests was about 65% for a total period of 86 min (sampling time corresponds closely to operating time). Since previous tests on the unit had been run with other methods of filter cleaning requiring gas flow downward through the filter media, and had yield efficiencies of 90% or greater, and since the blast cleaning method required upward gas flow, it was assumed that upward flowing gas was lifting the outer peripheral seal of slag wool, permitting some fume to bypass the filter bed. A second filter was made and the outer peripheral seal was improved by addition of a sand-filled

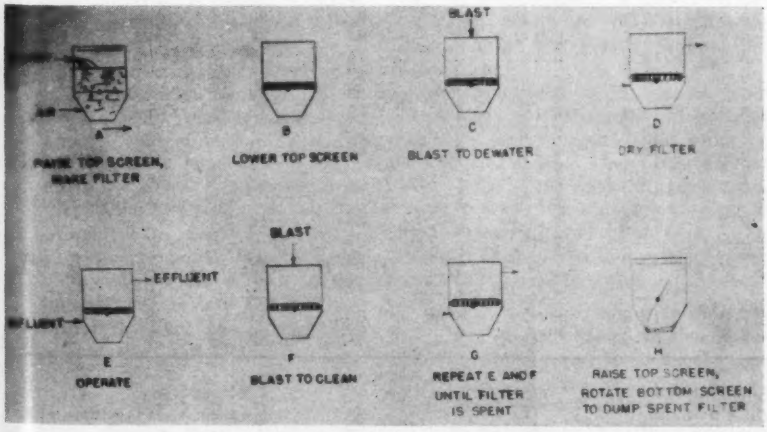

Fig. 10. Operation of open hearth furnace fume filter pilot plant 4C (blast).

Fig. 11. Pilot plant 4C (blast) installed on 13-ton electric furnace.

rubber tube placed beneath the top ring, on top of the filter, to increase compression at the outer edge and prevent gas leakage. Efficiency of this series was slightly higher, with an average of 71%. The third filter (tests 28–30) was hand packed with slag wool around the outer periphery, and average efficiency was again improved to 80%.

Tests 31 through 40 on the fourth filter were made by carefully packing the initial filter after formation very tightly with slag wool around the periphery. Average efficiency was increased to 87%, with a range from 79 to 96%, and throughout these tests (142 min) it was observed that no plume was visible from the unit fan stack, although the electric furnace stack was continually discharging a heavy visible plume. Present modifications on this unit are underway to improve the edge seal to eliminate the necessity of hand packing the periphery for each new filter.

Values of ΔR for the first three filters tested were about 3.2, 5.8, and 5.2 in H_2O, and based on these brief tests it appeared that a 5 in. Hg overpressure shock wave was removing sufficient amounts of accumulated fume to control filter resistance between the limits of about 6.5 and about 12 in. H_2O. Upon running the fourth filter test for an extended period, it was found that the cleaning was not as adequate as had first appeared to be the case, since the

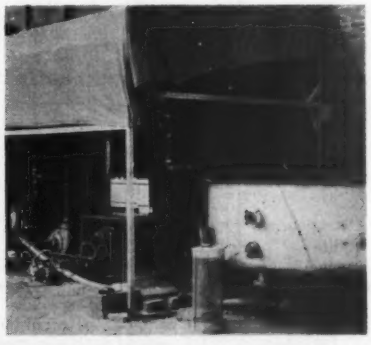

Fig. 12. Pilot plant 4C (blast) slurry storage tank and pump.

filter resistance after blast was increasing slightly as tests progressed. After 12 blasts at 5i n. Hg, ΔR had decreased from 6.3 to 5.3 in. H_2O, indicating that the filter was probably slowly plugging and the blast pressure was probably too low (c.f. Fig. 5 at low pressures). Higher pressures were tried to determine their effect (tests 39 and 40), and at $8^1/_2$ and 9 in. Hg, ΔR was increased slightly to 5.7 and 5.4 in. H_2O, respectively, but this was not felt to be satisfactory. Unfortunately, pressures above 9 in. Hg are not obtainable with the present pressure reservoir because of mechanical limitations. Minor modifications to the holdown device are being installed to permit higher pressures in shock waves for cleaning. We also intend to replace hand installation of blast diaphragms with automatic operation to reduce time required.

The pilot plant tests have demonstrated the feasibility of the shock wave filter cleaning method on a reasonable scale to permit further designs of a full scale high temperature furnace fume filter for open hearth fume. This method permits a fiber filter to be cleaned quickly (without appreciable disturbance) while it remains installed and operating, and should reduce the amount of handling of slag wool in the open hearth fume filter by a very large amount. On the basis of design parameters given above and checked in field tests so far completed, it is possible to clean a filter at least 10 times in place (and possibly more) before it is necessary to remove and constitute the filter bed. The fibers removed from the unit can be washed and short fibers can be removed by methods described previously,[14] so that a certain amount of the filter material can be returned to the system for reuse. Former tests have indicated eight to 10 "lives" for slag wool fibers used continuously in filtration pilot plants (i.e., 10 to 12% of the fiber must be replaced with each use). If as many as 25 or 50% of the fibers in blast cleaned filters are damaged it is conservatively estimated that fiber use will be increased 200 to 400%, or to 20 to 40 "lives." This would reduce presently estimated requirements of 4 tons per day of slag wool for a 250 ton open hearth furnace[14] to about one ton or less ($20/ton).

Summary and Conclusions

Laboratory and field investigations of the effects of shock waves on air and gas filters have shown that "weak" shocks (5 in. Hg) will remove approximately all material accumulated on the filter surfaces. By means of shock waves generated by the explosion of a simple paper diaphragm it has been possible to clean slag wool fiber filters up to 20 times when they have been used to filter a fine iron oxide fume. Filter resistance decrease (ΔR) occurs with the removal of accumulated fume by the action of the shock wave passing through the filter, and the amount of the decrease can be predicted from the cube root of the overpressure (P, in. Hg). If the filter and shock tube diaphragm one of the order of nine to one in area ratio, somewhat higher pressures are required to achieve cleaning comparable to that obtained when they are both of the same diameter. Laboratory tests have indicated the approximate characteristics of the shock tube necessary to permit scale-up to a 1600 cfm pilot plant filter unit, which has subsequently been tested with satisfactory results.

By examining iron oxide fume removed from filters by shock waves it was found that initial fume size (0.056 u CMD) was increased by a significant factor on the average (avg 0.096 u CMD), thus experimentally verifying the suggestion.

Other applications of shock wave cleaning for air filter surfaces can be investigated. For example, the Kling-Weidlein filter using steel wool mats for cleaning blast furnace gas[16] provided mechanical shaking for dust removal, but this approach was not used on a large scale since the shaking was not effective in removing deposited particles. This could be aided by addition of shock wave cleaning.

Shock waves offer a combination of desirable characteristics for particulate removal such as sonic velocity of the pressure wave, low material velocity, and ease of generation. A number of other filter materials that are fragile or ordinarily difficult to clean are presently under consideration for test, among them cloth fabrics of several types, porous metals, cellular (foam) refractories, electrodeposited screens, slag wool filter papers, and plates and other flat and curved surfaces.

(*Continued on page 330*)

Table IV—Shock-Wave Cleaning Tests on 1600 CFM Slag Wool Filter (2"–5#/cu ft) with Electric Furnace Fume

Test No.	Filt Vel[a]-fpm Init	Filt Vel[a]-fpm Final	In. Conc gr/cu ft	Filt Resist.[a]-In. H_2O Init	Filt Resist.[a]-In. H_2O Fin	Filt Resist.[a]-In. H_2O Aft Bl	Bl Press In. Hg	Eff %	Time Min	Remarks
22	118	109	0.70	5.0	8.0	4.8	5	70	37	New filter
23	114	101	0.61	4.8	9.4	—	—	61	49	Same filter
24	117	101	0.05	5.4	8.7	5.6	5	79	42	New[b]
25	116	82	0.16	5.6	14.7	6.6	5	64	35	Same
26	111	90	0.03	6.6	12.3	6.5	5	73	24	"
27	111	92	0.02	6.5	12.3	—	—	67	29	"
28	117	90	0.08	5.2	11.7	6.2	5	84	31	New[c]
29	114	95	0.04	6.2	11.7	6.5	5	74	18	Same
30	113	90	0.17	6.5	11.7	—	—	82	10	"
31	113	87	0.08	5.2	12.3	6.0	$4^1/_2$	93[e]	22	New[d]
32	112	87	0.04	6.0	12.3	6.1	5	79	12	Same
33	109	—	—	6.1	12.3	6.2	$5^1/_2$	—	1	"
34	106	89	0.19	6.2	12.3	6.4	6	86	3	"
35	106	89	0.06	6.4	12.3	6.5	$5^1/_2$	79	7	"
36	108	86	0.04	6.5	12.3	6.8	5	92	17	"
	108	—	—	—	—	6.5	5	—	—	— (extra blast)
37	108	89	0.04	6.5	12.3	7.0	$5^1/_2$	96	16	" "
	104	—	—	—	—	7.0	5	—	—	" "
38	108	85	0.02	7.0	12.3	7.5	5	88	22	" "
	106	—	—	—	—	7.0	5	—	—	" "
	106	—	—	—	—	7.0	5	—	—	" "
39	106	89	0.04	7.0	12.3	6.6	$8^1/_2$	86	14	"
40	104	90	0.02	6.7	12.3	6.9	9	81	28	"

[a] At gas temperature of 120°F, approx.
[b] Periphery of filter provided with rubber tubing seal.
[c] Periphery of filter packed with slag wool lightly by hand.
[d] Periphery of filter packed with slag wool heavily by hand.
[e] No plume visible from tests 31 through and including 40.

ODOR DETERMINATION TECHNIQUES *for Air Pollution* CONTROL*

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Webster has defined odor as "that property of a substance which affects the sense of smell." Smell is defined as "to perceive by the excitation of the olfactory nerves." These definitions leave much to be desired. The physiology of the olfactory sense, that is the mechanism through which a tiny area within the nasal fossae is able to receive an unlimited number of dissimilar odor stimuli, sometimes from remote distances and sometimes in dilutions as weak as one part per billion parts of air, constitutes a prime biologic mystery.

R. W. Moncrieff[1] has assembled 21 theories of olfaction sponsored by various investigators during relatively recent years. Some are fantastic, a few are impressive, but none is adequate for a real understanding of the complex ramifications of olfaction. Any acceptable theory, according to Moncrieff, must stand in relation to certain basic facts established for human olfaction. Some of the more interesting ones are:

1. Substances of different chemical constitution may have similar odors and substances of similar constitution may have dissimilar odors, but are usually similar.
2. The quality as well as the strength of odor may change on dilution.
3. The sense of smell is rapidly fatigued. Fatigue for one odor will not affect the perception of other dissimilar odors, but will interfere with the perception of similar odors.
4. Cases of preferential anosmia, i.e., ability to sense certain smells but not others, are not well established. Such cases occur, but little is known of them.

In general, the theories of olfaction agree that the substance, in order to be odorous, must be volatile, so that its molecules can make contact with the nasal orifices. There is some opinion that this is not necessary with insects.

There is general agreement that lipoid solubility is essential, that water solubility is helpful, and that odorants reduce the surface tension of their solvents.

Many consider unsaturation or residual affinity essential. There is also some relation between oxidizability and odor.

Due to failure to tie-up chemical constitution and odor, intramolecular vibrations are suspected as the cause of odor.

From the definition of odor, the basic facts established for human olfaction, and the theories of olfaction, the tremendous problems of inanimate detection and measurement of odors should be apparent. Instrumental methods of analysis are always based upon the measurement of some physical or chemical property of the substance to be analyzed. In order to measure odor, per se, it is necessary to measure some property which is characteristic of odor. What this property is, however, is unknown.

Inanimate instruments can be built to measure specific odors. They must measure some characteristic property of the odorant. These instruments still suffer from lack of sensitivity. A millionth of a microgram of some substances will produce an odor. The difficulties faced with measuring odor inanimately can be stated as:

1. Odor, per se, cannot be detected because odor has no single characteristic physical or chemical property.
2. If the odorant is to be measured, an instrument for each odor will be needed, extreme sensitivity will be needed, and mixed odors as well as unknown odors will impose a tremendous problem.

Organoleptic measurements, that is, measurements which make use of the sense organ of smell to detect odor, enable measurement of odor in general. Although this may appear to be a simple solution to the problem, it in itself presents many difficulties. The human nose is a very sensitive qualitative instrument, however, it does not measure odor quantitatively. Therefore devices are added to the nose in order to make detection quantitative. Matheson,[2] in his paper "Olfactometry, Its Techniques and Apparatus," has pointed out some of the difficulties and pitfalls of the organoleptic methods.

The more serious difficulties are related to the human nose which is used as the detector for these methods. The ability to smell differs between individuals and is said to differ within oneself at different times. However these are merely generalized observations. There seems to be no data asserting how great these variations are. This problem is in need of solution before much faith in absolute organoleptic measurements can be had. Perhaps the variations in the ability to detect odors by the human nose are insignificant, or at least within acceptable limits.

Organoleptic odor measurement devices can be divided into four main groups according to method or principle, namely the vapor dilution method, the vapor adsorption method, the liquid dilution method, and the rate of diffusion method.

In the vapor dilution method, the vapor of an odorous substance is used by some method to produce test dilutions of that odor for human appraisal, or more simply stated, an odor is diluted by odorless air to the threshold.

In the adsorption method, the prin-

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

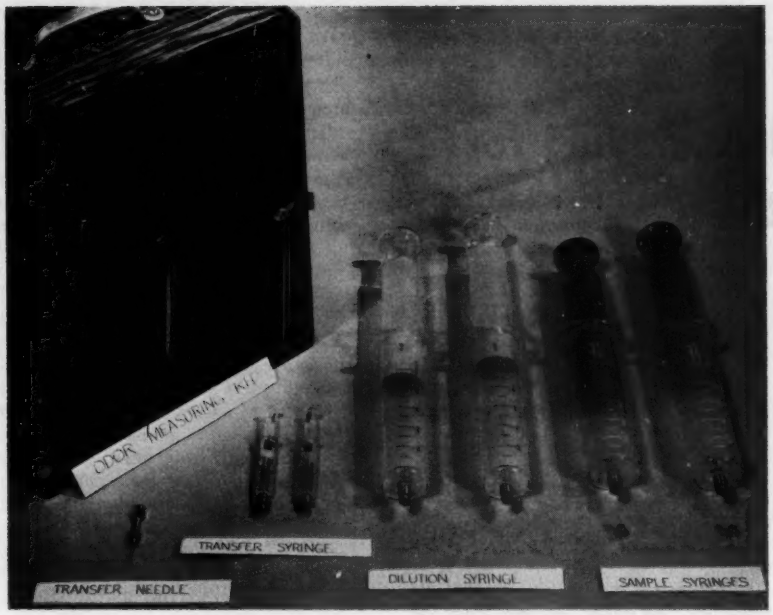


Fig. 1.

ciple is that of introducing a variable flow of odor vapor into an adsorbant column of known volume and measuring, by smell, the time required for the "break through" of the odorant.

In the liquid dilution method, an odorless solvent is used to make dilutions of the odorant material for human appraisal.

In the rate of diffusion method, the odorous material is placed at the end of a diffuser column which encloses odorless static air and the rate of diffusion is measured by human appraisal.

For a more elaborate breakdown of the organoleptic methods with examples of instruments, reference is made to a paper entitled "Olfactometry: Its Techniques and Apparatus" by J. F. Matheson, presented at the 48th Annual Meeting of the Air Pollution Control Association.[2]

In air pollution studies the three main facts concerning an odor occurrence which need to be known are: (1) how strong is the odor; (2) what is the source; (3) something of the quality of the odor.

The instrumental requirements for odor strength evaluations to be carried out by air pollution control personnel fall into two main categories, one for source strength measurements and another for ambient odor strength measurements. The instrument to be used at the source must be portable and have a fair degree of accuracy. There are several instruments available, for example: the "Osmo,"[3] the Nader Apparatus,[4] the Syringe Technique,[5] and the Fairs Wells Osmoscope.[6] The larger problem in control work lies in the measurement of ambient odor strength. For ambient odor strength determinations, it has been found that the instrument must be capable of rapid measurements. Ambient odors are often of very short duration, so that in order to get measurements, there is a fight for time. Ambient odors travel in air streams which move about with wind changes. Therefore the instrument must be extremely portable and not in the least cumbersome. Thirdly the instrument should require only one operator; few agencies can afford multiple personnel investigation of odor complaints. Finally, the instrument should be economical, so that each inspector can carry one with him at all times in the same manner in which he might carry an umbrascope for smoke emission detection.

Techniques we have found which are most suitable for air pollution control purposes, are the Syringe Technique, the Nader Apparatus,[4] the Flask Dilution Technique, and the Scentometer recently developed by the Cincinnati Air Pollution Control Bureau under U. S. Public Health Grant A-58-541.

The Syringe Technique (Fig. 1) is a vapor dilution method of the static type; that is, the vapor is caught in a syringe, removed in part into another syringe for static dilution to produce a test dilution of that odor for human appraisal. The use of this method is restricted to the measurement of odor strength at the source. Sensitivity necessitates its use only on nonambient odors. Advantages of this technique are its simplicity and its extreme portability. Its main disadvantage is that samples are first collected and then analyzed at a later time in a different place. On-the-spot evaluation is difficult.

The Nader Odor Evaluation Apparatus (Fig. 2) is a vapor dilution instrument of the continuous type; that is, vapor is incrementally removed from a controlled environment and bled continuously into a variable diluent air stream. The diluent air stream is supplied by air recovery through activated carbon. This instrument features a high degree of sensitivity and is portable. It, like the Syringe Technique, should be excellent for source odor strength evaluation. Unlike the syringe method, the Nader instrument does not lack sensitivity to weak odors and can be used to measure ambient odors. It makes on-the-spot measurements. Disadvantages of this instrument for ambient use are: an operator and an observer are required, it is awkward to use in the field, and the time requirement for measurements, about 10 minutes, is too long for many ambient odors. Ambient odors drift about to such a degree that the technique for detection must be capable of almost instantaneous measurement.

The Flask Dilution Technique is a liquid dilution method; that is, a mutual odorless solvent is used to make dilutions of the odorant material in flasks or sniff bottles. Odor appraisals are made directly from the mouth of an open flask. This is a comparator type method. It can be used in cases when complaints have been received but the conditions of the complaint have changed. An inspector may take dilutions of various odors, previously made, to the complainant for appraisal. The complainant can then choose the type of odor he complained of as well as its intensity. Advantages of this method are: simplicity, odor quality as well as strength is determined, and evaluation of odors do not have to be made at the time of the complaint. The big disadvantage of this method is that the odor as well as its strength must be remembered mentally until the time of the test. Another disadvantage is that the odorant must be known so that liquid dilutions can be made previously.

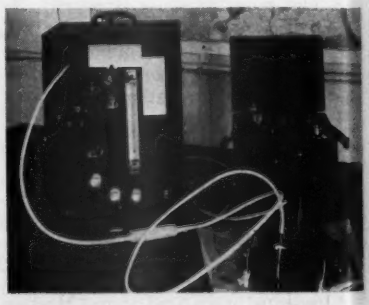


Fig. 2. Nader odor evaluation apparatus (modification).

Fig. 3. Scentometer and case.

The Scentometer (Figs. 3 and 4) is a vapor dilution instrument of the continuous type. It was designed to measure ambient odors and is at present in an early state of development. It combines the initial idea of the Fair-Wells dilution instrument with the concept of air recovery by activated carbon as used in the Nader Vapor Dilution Instrument. Odorous air is drawn through an activated carbon canister and becomes odorless. Odorous air is drawn through one of five openings in the side of the instrument. The odorous air then by-passes the canister and meets the odorless air from the canister in the mixing chamber. The mixture then passes through the nose pieces to the human observer. The odorous air inlets are regulated by the finger tips of the observer. The air is drawn through the instrument by action of the observer's lungs. The five odorous air inlets are of such diameter as to permit dilutions of 2, 4, 8, 16, and 32 parts total air to one part odorous air. It is therefore possible to distinguish between six odor levels. The advantages of this instrument are that it is extremely simple, economical, portable, operated by one person, and capable of rapid measurements.

This instrument has been extensively field tested in the Cincinnati area on rendering plant odors. All odor levels of this type odor were found. It has also been tested on chemical plant odors such as dimethylamine, mixed aniline, varnish, mercaptan, hydrogen sulfide, banana oil, lagoon (neutralizing) odors, and septic or outhouse-like odor. It has also measured odors associated with a spice manufacturer and a peanut roasting operation.

The original Scentometer has several design faults. The carbon canister, although presenting very little resistance to air flow, presented sufficient resistance to necessitate the use of very small odorous air inlets. For a dilution of 32 (its highest possible dilution) parts total air per part of odorous air, an inlet of 0.5 to 1 mm diameter was needed. The difficulties of maintaining an orifice of this size should be apparent.

In order to correct this difficulty, a design change was made in the Scentometer. Essentially the carbon canister was changed so that the area of the filter was increased 10 fold and the bed depth decreased five-fold. This new design will enable larger orifice diameters to be used for odorous air inlets. For example, a dilution of 128 will require an opening of $^1/_{16}$" diameter. As yet, this newly designed instrument has not been calibrated for air flow nor field tested. However, on the basis of the performance of the original, it is felt that this new model will be very adequate.

This instrument will replace the old system of mentally grading ambient odors according to descriptive terms of strength. Everyone should realize that a strong odor to one man may be overpowering to another because of his inability to separate strength from quality. With the use of the Scentometer, it is felt this discrepancy will be eliminated. The ultimate objective is to establish a legal definition of odor nuisance by reference to dilution levels as determined with the Scentometer.

With respect to source detection, the source in the majority of the cases is most obvious to the experienced air pollution officer. However, in some cases this is not so. A means of determining wind direction at point of odor measurement so as to locate the odor source would be helpful.

Fig. 4. Demonstration of field use of scentometer.

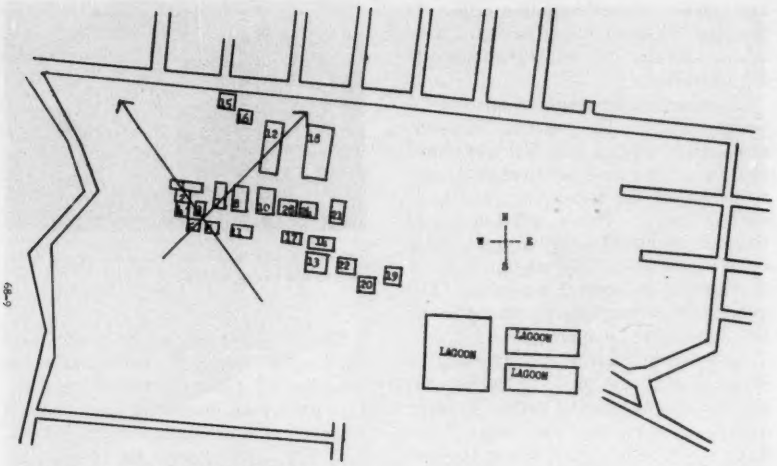
Fig. 5. Helium gas transfer from high pressure tank to low pressure tank.

The basic fact that odor travels down wind substantiates the fact that wind direction will point out the odor source. Low level wind directions, however, are subjected to much turbulence and therefore will give many faulty results. Most wind direction instruments measure wind direction only at a specific point. This type of measurement can be very faulty. Low flying balloons, however, will show wind direction all along its path and therefore give better results. Any size balloon will serve the purpose. However, it is best not to inflate the balloon to capacity. It should be inflated with sufficient gas so that it will rise slowly and indicate a low level wind direction. Greater portability for balloon inflation is accomplished using small, high pressure tanks (Fig. 5), which are filled with helium from the larger conventional helium tanks. A $5^1/_4$ in. $\times$ 8 in. tank, filled to a pressure of 100 lb/in.,^{2} will inflate approximately 10 small balloons (0.05 ft^3).

Sources can be detected by taking wind direction measurements during and at the odor occurrences. In this procedure, at the time of occurrence, the air pollution inspector should get into the area, release a gas filled balloon, study its path with a compass, and record the direction and the observation point. This data should then be put on a map of the area. A line of the odor path (determined from wind direction) is then drawn through the point of observation and extended back into the suspected area. If, at a later date, the same odor is found and the wind direction is different, by plotting this information on the same map, the source will in effect be triangulated by the two wind direction lines (Fig. 6).

The quality of odor as yet is a problem unattacked and is now out of the range of air pollution control regulations. The feelings on odor quality are very well put in an article entitled "Odor Control In Air Conditioning" which appeared in the April, 1957 issue of Progressive Architecture:[7]

"What can account for the likes and dislikes? Most people like the smell of flowers, most like the smell of a mild cheese; however, let that cheese odor appear in an egg and they will detest it. The smell of onions on a steak may be



Source detection by triangulation using wind directions taken during odor occurances. Figure contains two odorous air streams of the same odor which occured on two different days. Plants #3, #5, and #6 are detected as the probable source. (scale: 1 in. = 400 ft.)

Fig. 6.

pleasant, but the same smell on the breath of a companion may be horrible. The truth is that the brain does more than take information from the ends of the receptors and give a straight report on it; it minimizes some of the evidence, exaggerates other parts, lines it up with previous experience, takes a dozen other factors into account, and finally comes out with the answer 'I like' or 'I dislike.'"

From the standpoint of the Air Pollution Control Officer, quality of odor is too complex a problem to encounter. It should therefore be ignored in evaluating the nuisance value of an odor. Nuisance value must be related directly to odor strength. Enforcement personnel must take the stand that, regardless of quality, odor of a certain strength is a nuisance.

Summary

The physiology of the olfactory sense is a biologic mystery and therefore leaves much to be learned concerning the nature of odors. Due to this lack of knowledge, inanimate instrumentation for measurement of odor, per se, has not been conceived. Present inanimate instrumentation is based on measurements made on the known odorant. These methods are specific for one odor, suffer from lack of sensitivity, and are incapable of handling mixed and unknown odors.

Odor strength, per se, can be measured organoleptically. These methods suffer from the variations in the ability to smell. Of the present organoleptic measurement devices, the Syringe Technique and the Nader Dilution Apparatus are recommended for measurement of odor strength at the source. For measurements in the affected area of ambient odors, the Flask Dilution Technique and the Scentometer are recommended.

For the purpose of source detection of ambient odors and the gathering of proof of the source, triangulation by simple wind direction data is possible. The data must be gathered at the time of two different occurrences of the same odor with different wind directions.

Odor quality is such a problem, that for the purpose of present progress, it is best ignored.

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(*see page 344*)

SHOCK WAVE CLEANING

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Environmental Irradiation Test Facility*

ANDREW H. ROSE, JR., Chief, Engineering Research and Development Unit, and **C. STAFFORD BRANDT,** Chief, Agricultural Unit, (ARS—U. S. Dept. Agr.), U. S. Department of Health, Education, and Welfare; Cincinnati, Ohio

Environmental Irradiation Test Facility

Eye irritation, plant damage, reduction of visibility, and other related manifestations of urban air pollution are, on the basis of present evidence, due in part to photochemical and secondary dark reactions in the atmosphere involving oxides of nitrogen, hydrocarbons, and other organic compounds. The photochemical and secondary reactions responsible for these manifestations are initiated with the absorption of solar radiation. The effect of such absorption is to increase the energy level of the absorbing molecule above the level of the normal state, by an amount equal to the energy of the absorbed photon. Further, photochemical reaction results only when an electronic transition occurs which leads to disassociation of the molecule. As most of the electronic spectra lie in the visible and ultraviolet range, it is these regions which are photochemically important.

The modern internal combustion engine is probably the largest remaining single type of source of hydrocarbon and oxides of nitrogen for which no adequate control technique or device is available. Despite several years of intense research in this area, gaps of knowledge exist, and the information necessary for the ultimate solution of this complex problem can only be gained through a rigorous program of research and development. Employment of a precisely controlled environmental irradiation test facility can make possible or at least accelerate solutions of this problem and, further, will provide knowledge on new photochemical problems in air pollution which will surely arise in the future.

As indicated, the natural atmospheric environment is a complex, highly reactive system and its simulation requires the duplication of the photochemical and secondary dark reactions involving organic and inorganic substances. Reproduction of such a system in a laboratory irradiation chamber requires:

1. Control of temperature, humidity, and degree of purity of the air supply.
2. Control of concentration of the pollutant in the clean air supply at the point of introduction to the chamber and the subsequent mixing in the chamber.
3. Control of spectral distribution and intensity of the incident radiation of the air mass.
4. Control of exposure time of the air mass to radiation.

Further, knowledge of the behavior of surface effects is necessary as they relate to adsorption on the chamber surface, chemical reaction or decay of the gases, chemical reactions catalyzed by the chamber surface, and the formation of new components from the original precursors.

An environmental irradiation test facility embodying these requirements has been developed at the Robert A. Taft Sanitary Engineering Center, Fig. 1. This facility is composed of five major components: dynamometer unit, dilution air purification unit, exhaust dilution assembly, irradiation chambers, and the exposure facilities to evaluate air pollution effects of the irradiated pollutants.

Source of air pollutant to be employed in the initial studies will be furnished by an automotive internal combustion engine. Duplication of the exhaust discharge from various representative driving patterns is accomplished by the use of a chassis dynamometer modified such that it is capable of reproducing all conditions of deceleration, acceleration, cruise and idle, as well as various combinations on a cyclic basis. Measurement of engine speed, manifold vacuum, carburetor air

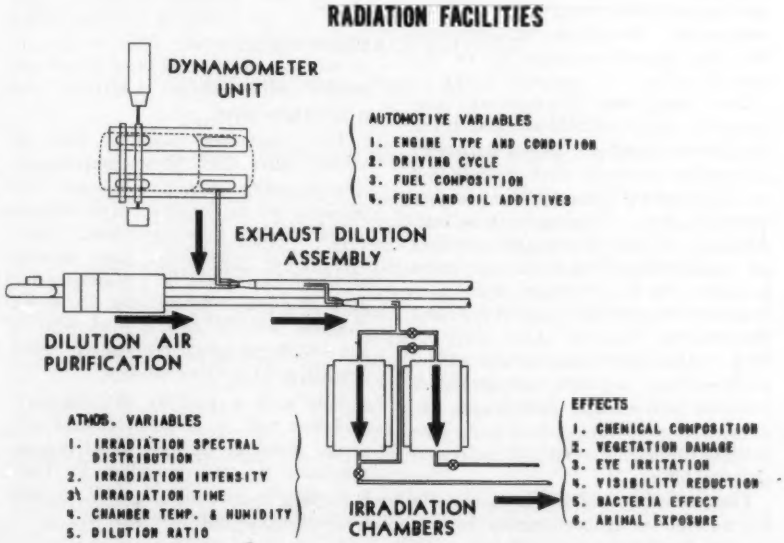

Fig. 1.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1960, Los Angeles, Calif.

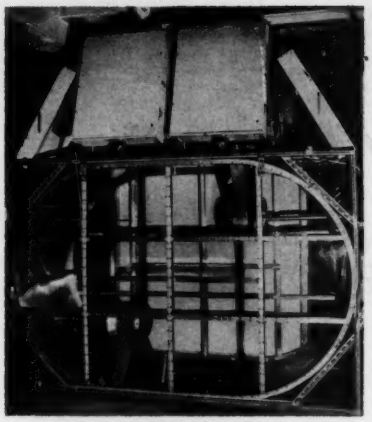

Fig. 2. Irradiation chamber.

flow, and throttle positioning, made during actual road operations, will be used as the basis for simulating driving patterns on the dynamometer.

Two major modifications of a standard 150 hp capacity hydraulic type chassis dynamometer were required in order that variations in the deceleration cycle could be made and that the power absorption capacity of the dynamometer could be more closely controlled. Changes in the deceleration cycle are effected by coupling a slave engine assembly through an overrunning clutch to the power absorption roll of the dynamometer allowing controlled motoring of the test engine. Horsepower of the dynamometer is established by controlling the amount of water in the hydraulic power absorption unit utilizing a positive displacement piston in a closed hydraulic system. Varying the capacity of this closed system by positioning the cylinder piston varies the water content in the power absorption unit and results in variations in the horsepower absorption by the dynamometer. Deviations in horsepower with this control technique are on the order of 1.0%.

The cleanliness, temperature, and humidity of the dilution air used in the irradiation chambers, should as nearly as possible duplicate that encountered in clean urban atmospheres prior to contamination. To achieve these conditions, a $7^1/_2$ ton capacity refrigeration air conditioning system is employed to control the temperatures of the dilution air between 60° and 110°F and the relative humidity from 35% to 90% within this temperature range. Hydrocarbon, organic and inorganic gases, as well as solid particulates, are reduced to acceptable levels using particulate filters followed by activated charcoal filters.

Concentrations of hydrocarbon in the automotive exhaust under various driving conditions and patterns vary in the range of 700–7000 ppm.[1] This requires the use of dilution ratios of 600:1 to 3600:1 in order that the hydrocarbon concentrations in the irradiation chamber approximate those of urban atmospheres. To meet these wide conditions, the dilution system was constructed as a two-stage unit with each stage operating at flow rates between 100 cubic feet per minute and 250 cfm. Dilution in the first stage can be varied between 10:1 and 60:1 while the second stage operates at a fixed dilution ratio of 60:1. To prevent contamination of the dilute automotive exhaust by pumping or ingress of unfiltered air, the entire dilution system operates under sufficient positive pressure to convey the gases through the dilution system, the irradiation chamber, and the exposure facilities. Introduction of the exhaust gases at low pressures into the dilution system at higher pressures, as well as the movement of the gases from the first dilution stage to the second dilution stage, is accomplished by introducing the gas into zones of sufficiently low pressure, created at the venturi throat, to cause flow.

Consideration of existing environmental irradiation test facilities[2, 3, 4] led to the development of a facility employing two irradiation chambers constructed of aluminum with Mylar windows and having a volume of 335 cubic feet each. The chambers are arranged for either serial or parallel operation to facilitate replicate testing of a given gas stream under identical conditions or with variations in irradiation time, spectral intensity, and spectral distribution. Each chamber, Fig. 2, embodies internal recirculariza-tion utilizing two tube-axial fans. Rapid mixing, necessary if the chamber performance is to approach the behavior of an ideal dilution volume, results from the jet action of the fans which causes approximately 50% of the gas at the fans to be accelerated ahead and mixed, under turbulent conditions, with a new gas volume.

The irradiation chambers were designed such that their performance characteristics would approach the behavior of an ideal dilution volume under constant flow conditions. Under such ideal conditions any element of input gas would be instantaneously and completely mixed into the entire chamber volume and any element of the output gas would be perfectly representative of the entire volume.

If in such a chamber of volume, V, and flow rate, q, a small amount of a given material is introduced instantaneously to the chamber at time, $t = o$, the concentration, C, of this material in the output would be

$$C = (C_o e)^{-kt} \qquad (1)$$

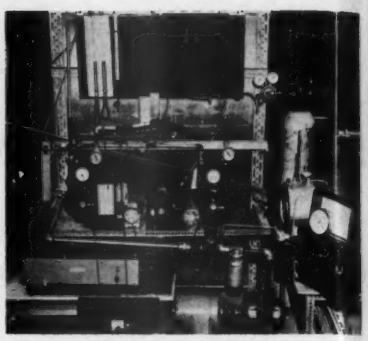

Fig. 3. Chamber performance test facility.

where

$$k = q/V$$

If, however, we introduce into any empty chamber at time, $t = o$, a constant flow of gas of concentration, C_i, of a component of interest, the concentration, C, in the chamber and in the output gas stream at any time, t, would be

$$C = C_i\,(1\text{-}e^{-kt}) \qquad (2)$$

These solutions describe the operation of the idealized chamber under ideal conditions.

A series of tests at flow rates of approximately $1^1/_2$ cfm, 2 cfm, and $2^1/_2$ cfm were conducted, employing dynamic conditions of constant flow at an inlet CO_2 concentration of 5%, to determine the deviation of the performance characteristics of the chamber from the ideal conditions. Flow measurements, both chamber inlet and outlet, were made using two calibrated bellows meters and were maintained at a maximum deviation not to exceed $^1/_2$%, Fig. 3. CO_2 concentrations of the chamber outlet were recorded continuously using a nondispersive infrared gas analyzer operating at a wave length of 4.2 microns; inlet concentration was checked periodically during the test. CO_2 was used as the calibrating gas since, as a nonpolar compound, the surface effects were minimal and could be disregarded. To evaluate chamber performance characteristics equation 2 was transformed to express time in terms of fraction of the concentration of the outlet to inlet gas, such that

$$-kt = \ln C_i - C/C_i \qquad (2a)$$

Raw data for each run was plotted using a least square fit for the curve. A typical plot is shown in Fig. 4.

Variation of the chamber performance from the ideal was determined on the basis of the deviation of the experimental slope, obtained by the least square fit, from the theoretical, where $k = q/V$, and on the basis of experimental deviation of percent concentration of the outlet to inlet gas at

time zero. The experimental procedure used in the calibration is such that errors within the experiment are confounded and the individual error in the measurement of chamber volume, chamber flow, and gas concentration, cannot be determined individually. The maximum deviations indicated are within the range of experimental error and the chamber is considered behaving as an ideal dilution volume under constant flow conditions, within this error.

For precise determinations of the air pollution effects and investigations of the photochemical and secondary dark reactions causing these effects, it is necessary to express mathematically the exposure time that any element of gas output has been subjected to irradiation under any given conditions in the chamber. Obviously with the chamber performing as an ideal dilution volume part of the output sample entered the chamber immediately prior to sampling while part has been in the chamber since the start of irradiation. Two expressions for exposure time are possible:

1 Half time, $T_{1/2}$, such that 50% of the molecules have been in the chamber for time, $T_{1/2}$ or more, and 50% for time, $T_{1/2}$ or less.
2 Average time, T_a, as the average of the time all molecules of a given sample have been in the chamber.

Consider the chamber performing as an ideal dilution volume under constant flow conditions, q, of a gas of concentration, C_i, where at zero time the chamber is empty. In any small sample withdrawn at time, s, measured from zero time, the average exposure time, T_a, would be

$$T_a = \frac{1}{k} - \frac{se^{-ks}}{1 - e^{-ks}} \qquad (3)$$

where again $k = q/V$. Under such conditions the half time exposure, $T_{1/2}$, would be

$$T_{1/2} = \frac{\ln 2}{i} - \frac{\ln (1+e^{-ks})}{k} \qquad (4)$$

A plot for average exposure time vs sampling time for 1.3 cfm and 4.0 cfm is shown in Fig. 5.

It is anticipated under actual operating conditions that the chamber would be initially loaded with the component of interest to an equilibrium concentration equal to the chamber inlet concentration, C_i, in order to reduce the chamber operating time such that the average exposure time would remain relatively constant for a finite sampling interval. Under such conditions the average exposure time, T_a, would be

Table I—Summary of Performance Characteristics Data

Flow	Theoretical Slope	Experimental Slope	Deviation	Experimental Intercept	Deviation
cfm	q/V Actual	q/V Apparent	%	% of Theoretical	%
2.801	8.361×10^{-3}	8.246×10^{-3}	−1.38	99.91	−0.09
2.798	8.352×10^{-3}	8.232×10^{-3}	−1.44	100.20	+0.20
2.055	6.133×10^{-3}	5.919×10^{-3}	−3.49	99.86	−0.14
2.039	6.086×10^{-3}	5.718×10^{-3}	−6.05	99.88	−0.12
1.631	4.868×10^{-3}	4.749×10^{-3}	−2.44	100.09	+0.09
1.685	5.030×10^{-3}	4.991×10^{-3}	−0.78	100.19	+0.19

Intercept $\left(\frac{C_i - C}{C_i}\right) \times 100 - T = 0$

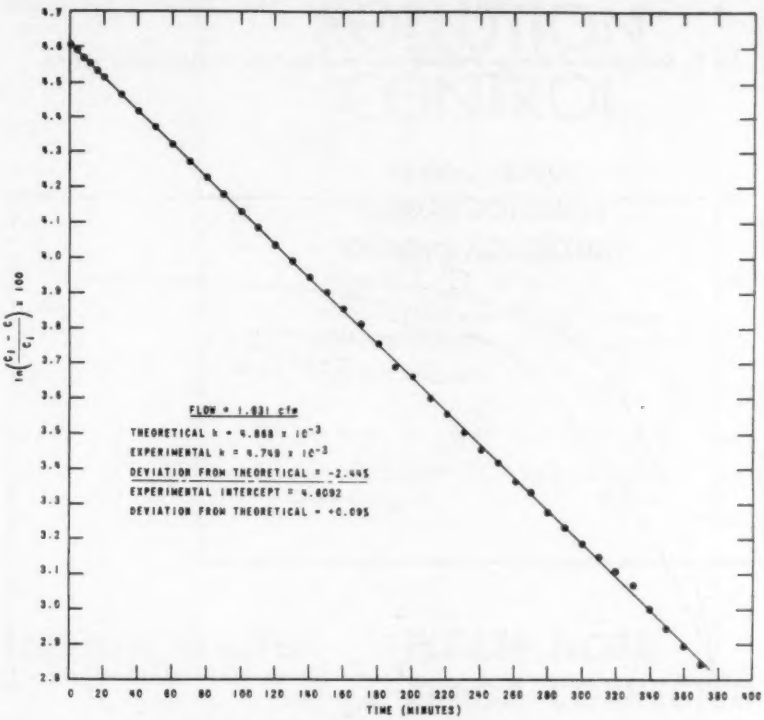
FLOW = 1.631 cfm
THEORETICAL k = 4.868 x 10⁻³
EXPERIMENTAL k = 4.749 x 10⁻³
DEVIATION FROM THEORETICAL = -2.44%
EXPERIMENTAL INTERCEPT = 4.8092
DEVIATION FROM THEORETICAL = +0.09%
TIME (MINUTES)

Fig. 4. Fit of experimental data to theoretical form.

TENTATIVE PROGRAM

1960 East Central Section APCA Meeting

Sheraton Cadillac Hotel—Detroit, Michigan

Thursday—September 22 and Friday September 23

Keynote Address, "General Appraisal of Air Pollution Problem"
Paper, "Trends in Air Pollution Legislation"
Panel Discussion: "The Air Pollution Control Team"
Luncheon—Speaker, "Psychology of an Enforcement Program"
Symposium
Paper, "The Present Status of Research on Air Pollution Health Relationships"
Paper, "Industrial Uses of Radioactivity and Its Control"
Business Meeting—APCA Members Only
Paper, "Current Status & Future Work on Vehicle Emission Control Devices"
Paper, "Carbon Monoxide As An Air Pollutant—A Factor in Traffic Accident Causation?"
Panel Discussion: "Air Pollution Control—A Basic Element in a Company Expansion or Relocating Program"
Luncheon—Speaker, Arnold Arch, Executive Secretary, APCA

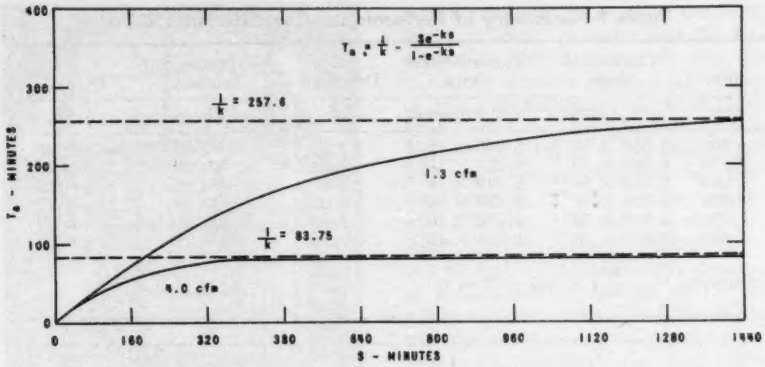

Fig. 5. Dependence of average irradiation time on sample time. Chamber empty at T = 0.

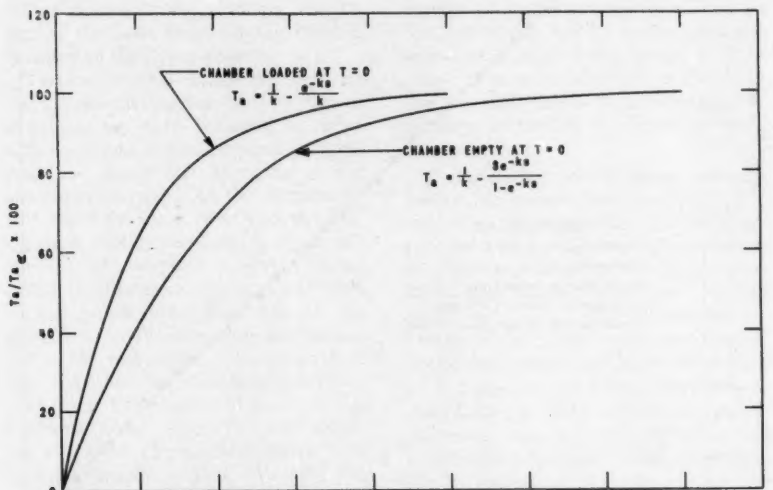

Fig. 6. Generalized dependence of average irradiation time on sample time.

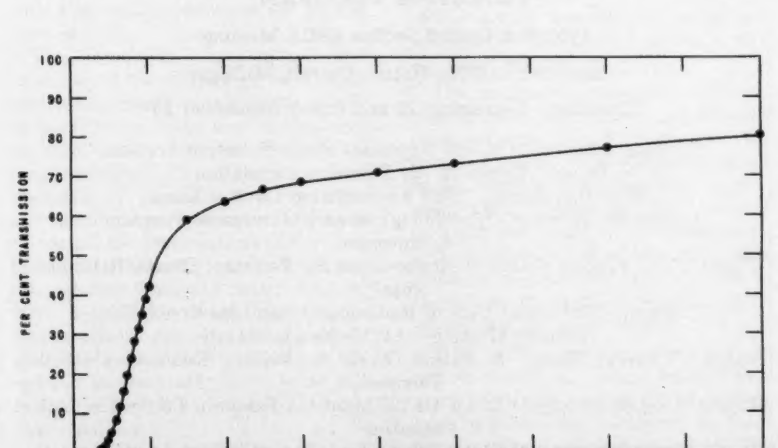

Fig. 7. Transmission of mylar—3 mill type D.

$$T_a = \frac{1}{k} - \frac{e^{-ks}}{k} \qquad (5)$$

For these conditions the half time exposure concept is not valid for all conditions of sampling time and is not applicable.

For both chamber conditions, i.e., initially empty or loaded to equilibrium concentration, the limit on average exposure time, T_a, as sampling time, s, approaches infinity would be

$$\lim_{s \to \infty} T_a = 1/k \qquad (6)$$

and for half time exposure, $T_{1/2}$, would be

$$\lim_{s \to \infty} T_{1/2} = 0.693/k \qquad (7)$$

A generalized plot illustrating dependence of average exposure or irradiation time on sampling time, Fig. 6, is developed with average time expressed as a percent of the limit of average time versus sampling time expressed in units of the average time limit. The use of a chamber initially loaded to equilibrium concentration as illustrated in Fig. 6 would reduce the time of operation prior to sampling by 35% to 45%. For long average irradiation time experiments, such a reduction amounts to an appreciable saving of time.

Since the exposure time of the air mass to irradiation is dependent, during dynamic chamber operations, on flow rate through the chamber, any factor affecting this flow rate must be considered. The most probable source of variation in flow rate would be chamber leakage. A study of leak rate was made by building the static pressure in the chamber, with all ports sealed, to 5 in. water gauge and recording the rate of pressure decrease with time. Calculations of volume changes with time, corrected for temperature and barometric pressure variations, indicate the average leak rate to be 0.004 cubic feet per minute. This is only 0.4% of the minimum design flow rate of 1 cfm.

The most recent evaluation of the relative importance of various photochemical reactions likely to occur in the atmosphere[5] concludes that absorption between 4700 angstroms and 2900 angstroms by NO_2, organic nitrites, alpha diketones, and possibly metallic oxides cause most of the photochemical reactions observed in urban atmospheres. In attempting to duplicate this solar radiation effect using artificial radiation, care must be exercised that the cut-off point is established at approximately 2900 angstroms to 3000 angstroms since some of the above reactions may, in the lower wave bands, follow different reaction

routes, form different compounds, or produce different concentrations of similar compounds. Further, some compounds which are nonreactive under solar radiation may become reactive at the lower wave lengths of radiation.

Incident irradiation of the air mass within the chamber is supplied from sources external to the chamber, passing through windows of three mill Type D Mylar. The source of irradiation is two banks of 70 fluorescent tubes each, mounted in two external cavity reflectors. The 96 in. T-8 tubes used are operated on T-12 ballasts which supply a 50% overload to increase the incident irradiation intensity. Three types of tubes, black light, warm white deluxe, and blue, are employed in varying proportions to approximate solar radiation from 4500 angstroms and 2900 angstroms.

The choice of the window material is a compromise among many factors, including spectral transmission, strength, surface absorption, and diffusion. Strength and surface characteristics of the Mylar are adequate for this purpose. As shown in Fig. 7, the spectral transmission curve is smooth with a cutoff point between 3200 angstroms and 3100 angstroms. While this point is somewhat higher than the solar cutoff, the total loss of solar energy through the Mylar between 4000 angstroms and 2900 angstroms is only 3.5%.

Preliminary tests and calibrations made on the facility indicate that the design objectives have been fulfilled in that control of the source of contamination can be maintained, flexibility of operation for replicate testing under identical or variable conditions is accomplished, chamber performance approaches the behavior of ideal dilution volume, irradiation exposure time is mathematically defined, and irradiation intensity and distribution is controlled.

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SECTION HI-LITES

At a dinner meeting in June, the Niagara Frontier Section presented Roy P. Warren with their annual Achievement Award. Mr. Warren, who has been called "the one man in the Buffalo area who knows more about the subject than anybody else," was commended for his contributions in combatting the problems of pollution presented continually by new contaminents and new process. Although retired from the Buffalo Forge Company where he was head of the air cleaning division, Mr. Warren still acts as a consultant on aid pollution problems and recruits engineering personnel for the firm.

George Brandt, chairman of the section, made the presentation and called upon industrial and civic awareness of the need for air pollution control. Erie County, he noted, is awaiting a report by the State Air Pollution Control Board on area problems. A similar survey on an upstate New York community has revealed that 40% of existing air pollution was from the general public, rather than industrial causes.

PLEASE NOTE; ERROR CORRECTED

A relatively important error has been noted in the article, "Design and Performance Characteristics of High-Velocity High-Efficiency Air Cleaning Precipitators," by Harry J. White and William H. Cole, published in the June, 1960, Volume 10, No. 3, issue of JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, column 3, page 240. The equation for w_2 is shown on p. 240 as follows:

$$w_2 = \frac{(0.90)(33)(50)(0.35 \times 10^{-4})}{(6.28)(1.8 \times 10^{-4})} \times \left(\frac{0.86 \times 10^{-5}}{0.35 \times 10^{-4}}\right) \times \frac{1}{30.4} = 1.90 \text{ fps}$$

This equation should read as follows:

$$w_2 = \frac{(0.90)(33)(50)(0.35 \times 10^{-4})}{(6.28)(1.8 \times 10^{-4})} \times \left[1 + \left(\frac{0.86 \times 10^{-5}}{0.35 \times 10^{-4}}\right)\right] \times \frac{1}{30.4} = 1.90 \text{ fps}$$

AUTOMOTIVE *Air Pollution:* *a* SYSTEMS APPROACH*

STUART L. RIDGWAY and **JOHN C. LAIR,** Members of the Technical Staff, Research Laboratory, Ramo-Wooldridge a division of Thompson Ramo Wooldridge Inc., Los Angeles, Calif.

Systems Engineering is a phrase with many definitions. As a field it grew out of the need to consider complicated weapon systems interacting with a complicated environment. With perhaps some injustice to its more enthusiastic advocates, it might be defined as recognizing a need, and drawing a large schematic diagram connecting black boxes, often with devious and wonderful functions, whose interaction with the environment is the desired one, and parceling out to someone else the tasks of making each black box perform. We would be much amiss if we claimed to have taken a careful look at the broad picture of the smog problem, detected the pressing need for a particular black box, and proceeded with its development as our contribution. Instead we began with the acute personal conviction that automobile exhaust was the villain, that its control needed a brute force approach, and with an idea as to how it might be done. But as knowledge and experience have accumulated we find ourselves forced to begin to consider the relations among many other things and to practice Systems Engineering.

The Afterburner System

Accept for the moment that auto exhaust is the overriding source of pollution, and imagine three million black boxes on the cars of Los Angeles. With each engine that is running there is associated a fire in the black box, and hot exhaust gas mixed with air is fed to this fire to keep it going. The unburned hydrocarbons, aldehydes, alcohols, acids, and carbon monoxide from the engine are fuel to the black box, and the poorer the condition of the engine the more abundantly it supplies this fuel. Passing through the flame in the box, the fuel is oxidized to CO_2 and water, which is the desired result. The uppermost system requirement is seen to be that the flame be kept alive. Now in fact, there are conditions of engine performance, desired by the motorist, which threaten the flame with fuel starvation by providing too cold and lean a stream to the black box. The system engineer's first temptation is to meet these conditions by enriching the stream with supplementary fuel from the gas tank. His second thought is better: get a flame going, then use the heat from the burnt gas to heat further unburnt exhaust to the point that lean though it may be it shall burn. Thus to the first black box is added a second, a heat exchanger that transfers the heat from the fully burnt and about to be discharged gas to the cool incoming gas.

In order to design the first black box one needs to know the necessary temperature, compositions, and reaction rates inside of the reactor that will reduce the concentrations of pollutants to an acceptably low level, and oxidize enough of the combustible to yield the heat necessary to keep things going. Although the reactions among the combustibles, oxygen, and chain carriers are very complicated, it might be hoped that the over-all rate might be controlled by few critical steps whose response to combustion condition might be simple. Measurements were made of the change in combustible content in a homogeneous reactor as a function of temperature. Fig. 1 shows a plot of the log of the reaction rate constant as a function of the reciprocal of the absolute temperature, which indicates that for practical engineering purposes the over-all reaction has a simple Arrhenius dependence upon temperature and is first order in combustible concentration. From these data one infers that for stable and satisfactory operation of the reactor the final temperature of the burnt gas should be of the order of 1550°F, and the minimum stable operating temperature for reactors of reasonable volume and without catalysts is between 1400° and 1450°F.

Consider the attempt to fit such a black box into the exhaust stream of an automobile. The automobile engine exhaust is not the chemical engineer's dream of the ideal process stream that he would care to design a plant for. The exhaust gas flow from an engine can vary from 5 to 200 scfm, and its combustible content has large planned varia-

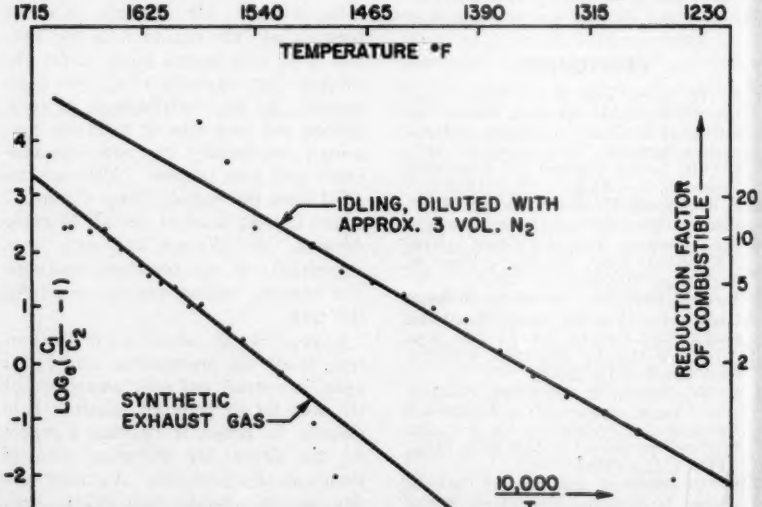


Fig. 1.

* Presented at the 52nd Annual Meeting of APCA, Statler-Hilton Hotel, June 21–26, 1959, Los Angeles, Calif.

tions, in addition to those variations due to malfunction of the engine system. The simple black box begins to grow, with auxiliary black boxes and controls.

The fundamental design problem begins with the choice of size of heat exchanger for preheating and reaction volume for combustion. The immense variability of exhaust flow and composition would seem to make this first engineering choice difficult, but one soon learns two properties of this kind of an exhaust control device. It is first obvious that an energy investment must be made, since a cold heat exchanger cannot preheat exhaust gas. If the reaction goes out, the flow of exhaust cools the device quickly, and the starting heat energy must be replaced. If the operation regime that required the most heat exchanger were an infrequent one, the device could be allowed to go out occasionally, and then restarted. If the properties of automobile engine exhaust are examined, the most difficult regime for this type of system is found to be 30 mph cruise. Since this is a very common regime, enough heat exchanger must be provided to handle 30 mph cruise. Other regimes of operation will then have more than enough heat exchanger, and the effect of reserve heat exchanger capacity is to cause a slow rise in the operating temperature levels. One is here presented with the choice of using materials that would withstand these temperature excursions, or of introducing a temperature control. Since stainless steels which are relatively economical materials of high temperature construction reach service limits for reasonable life in the neighborhood of 1600–1700°F, it seems best to control temperature by modulating the efficiency of the system by bypassing part of the exhaust gas past the heat exchanger directly to the combustor. Thus there is introduced into the system a temperature sensing element, and a bypass control valve.

The completion of combustion usually requires additional air. It was shown previously[1] that the optimum combustor is a homogeneous reactor. The gas in the reactor has everywhere the composition of the final exhaust, and the reactivity of this state is decisive for the performance of the device.

This enables one to state simply that enough air should be added to insure an adequate reaction rate in the final state of the gas-air mixture in the combustor. Five percent excess air over stoichiometric in the final exhaust seems satisfactory. Accepting this condition one observes that an air supply system has to supply an amount of air, against a variable afterburner back pressure, whose desired variation is a function of the variation of total throughput of the engine as the engine is cycled through its transients in driving through traffic, and also a function of the variable air-fuel ratio provided by the carburetor to the engine. One solution has been to provide a pump that delivers the amount of air needed at full throttle as a function of engine speed, and to discharge unneeded air at part throttle, this discharge being controlled by available parameters of the engine that contain the necessary information. Afterburner back pressure, engine speed, and manifold vacuum are sufficient to locate the operation point of the engine and the afterburner such that a control system that takes cognizance of these variables can meet the specifications.

Finally, one notices that the operation of the system depends upon borrowing the energy necessary to preheat the exhaust gas to a reactive temperature. An initial capital investment of heat energy into the heat exchanger must be made. If the engine is run under sufficiently rich conditions, the exhaust gas will be inflammable even at room temperature as a consequence of the high hydrogen and carbon monoxide content resulting from the very partial combustion in the engine. Fortunately an automobile engine comes equipped with an automatic choke that enriches the mixture for the benefit of starting the engine. Except in cold weather, the normal enrichment is not quite sufficient for the needs of the device, so that an additional control is needed to delay the release of the choke until the energy down payment has been made.

One may be tempted to wonder at the necessity for the complex of controls and auxiliary functions that have to be added to keep such a simple thing as a flame properly going. Clearly such complexity will add to cost, but if one looks about him one finds in this modern world many complex devices whose complexity we ignore because they behave well, and are manufactured at a low cost. Complexity costs particularly in the engineering effort and time necessary to develop an inexpensive and reliable device. Considering these things, and comparing this type of device with a catalytic device, one recognizes that it is more complex, and that it either works well, or not at all. The flame is going, or is out. If the flame is maintained, then a very good job is done of removing hydrocarbons and other combustible pollutants, averaging better than 90%, or in absolute terms the emission is reduced below 25 ppm hydrocarbons measured with a Liston-Becker non-dispersive infrared analyzer,

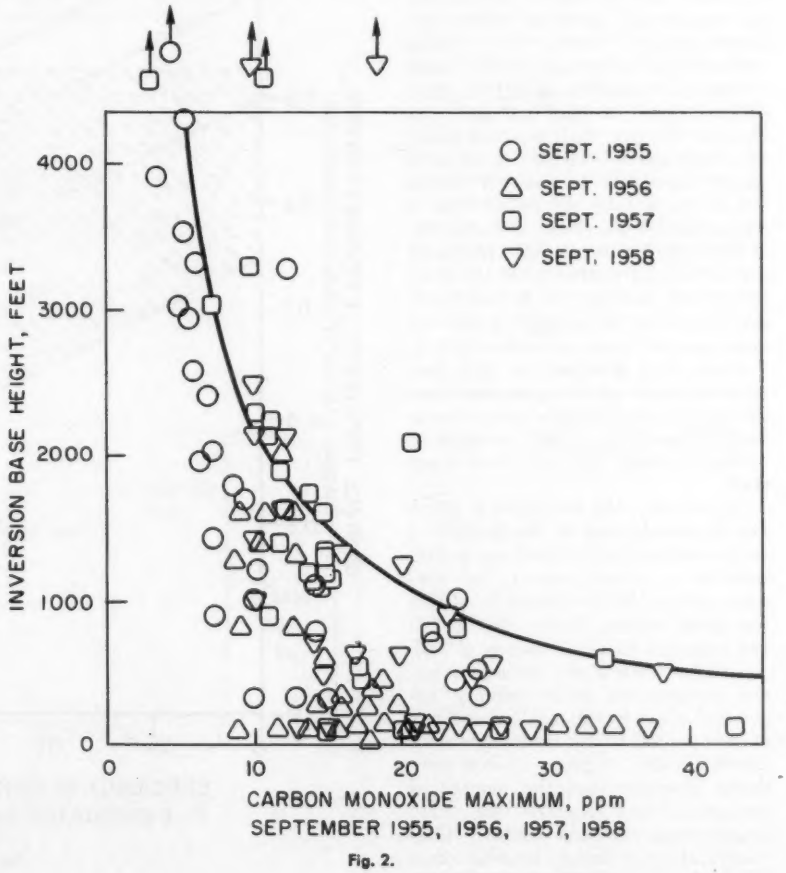


Fig. 2.

expressed as hexane. Is this quality necessary? We will now attempt to analyze the natural meteorological modulation of the concentration of air pollution to form an estimate of the results that might be hoped from man's further control of his pollution activities.

The Smog Season

It has been the situation of the Southern California littoral, washed by a subtropical ocean, that human activity could multiply here without the inconvenience of suiting itself to a procession of the seasons, and especially without submitting to the restraints and discontents of winter. That household word implies muffled growth and reduced tempo, increased costs and enlarged uncertainties, cold, ice, and snow. But all these characteristics and effects of a typical winter season have auspicious counterparts in the Los Angeles Basin, where a relatively seasonless year permits unbridled activity, and a growing enterprise requires no protection against extremes of climate but may enjoy bland airs and plenty of sunshine. So far, the logic rests securely on the natural meteorology of the Basin, and it has been our human tendency to act on this logic by establishing ourselves here, annually increasing our number and our exertions while we have exploited the year-round possibilities for coming and going by automobile. Unfortunately, under the benign meteorological conditions of our choice we are now numerous enough to make weather of a new kind and there has emerged the fact, then the conception, of a *smog season*. Though it varies in length from year to year, it always seems interminable in course, like a winter, and is universally a discontent. It is imposing certain poorly understood and ill defined restraints on all of us, but we acknowledge it to be man made, and there has accordingly arisen the large question of our restraints upon it. Pursuing this question, we may proceed to locate the smog season more definitely in the calendar year, then to extract from it that month in which its marked characteristics will most repay study.

On any day, the air pollution above Los Angeles depends on the strength of certain meteorological conditions and results in a certain severity of consequences for the life beneath it. Using judiciously chosen limits, the APCD has organized the observations of both conditions (weak winds, low inversions), and consequences (poor visibility, experience of eye irritation), by frequency of days per month, for the months since January, 1955. A glance at their summaries discloses that the months of smogginess and concern are July, August, September, and October. Conversely, the least smoggy interval comes just six months earlier at the beginning of a year. How are these most and least objectionable seasons related? As to frequency of adverse conditions, we may very roughly say that meteorological factors conspire against us about four times as frequently in season as out. Unpleasant effects are harder to measure and discuss, but are at least twice as frequent in season as out. Moreover, these effects are perhaps twice as intense in season as out, so that it has some small meaning to say that the total unpleasantness of the smog season is not less than 4 times that of the first months of the year. Finally, there exists a formal criterion of extreme air pollution in the "alert" apparatus of the APCD, by which an alert is invoked whenever a local ozone concentration is observed to be 0.5 ppm or more. The procedure was instituted in July, 1955, since which time there have been called two alerts in June, two in July, seven in August, 13 in September, and three in October. The prominence of September is brought out further when the durations of alerts are added by months with the following result:

June	2.7 hours
July	1.2
August	4.2
September	15.5
October	3.3
November	1.4
December	0.6

which tabulation discredits September by a larger total time of high ozone concentrations than all the rest of the year combined. Many who are technically interested in Los Angeles air pollution problems will recall that the maximum of all ozone maxima was recorded at 0.9 ppm on September 13, 1955. In any event, the month of September is unlikely to be displaced as the heart of the smog season, and we now restrict the argument to September phenomena as the worst case in our problem, having peak values which should not be suppressed in a welter of averages. Both on the plane of analysis and of engineering, measures adequate to September phenomena will be more than adequate to the milder situation of the other months.

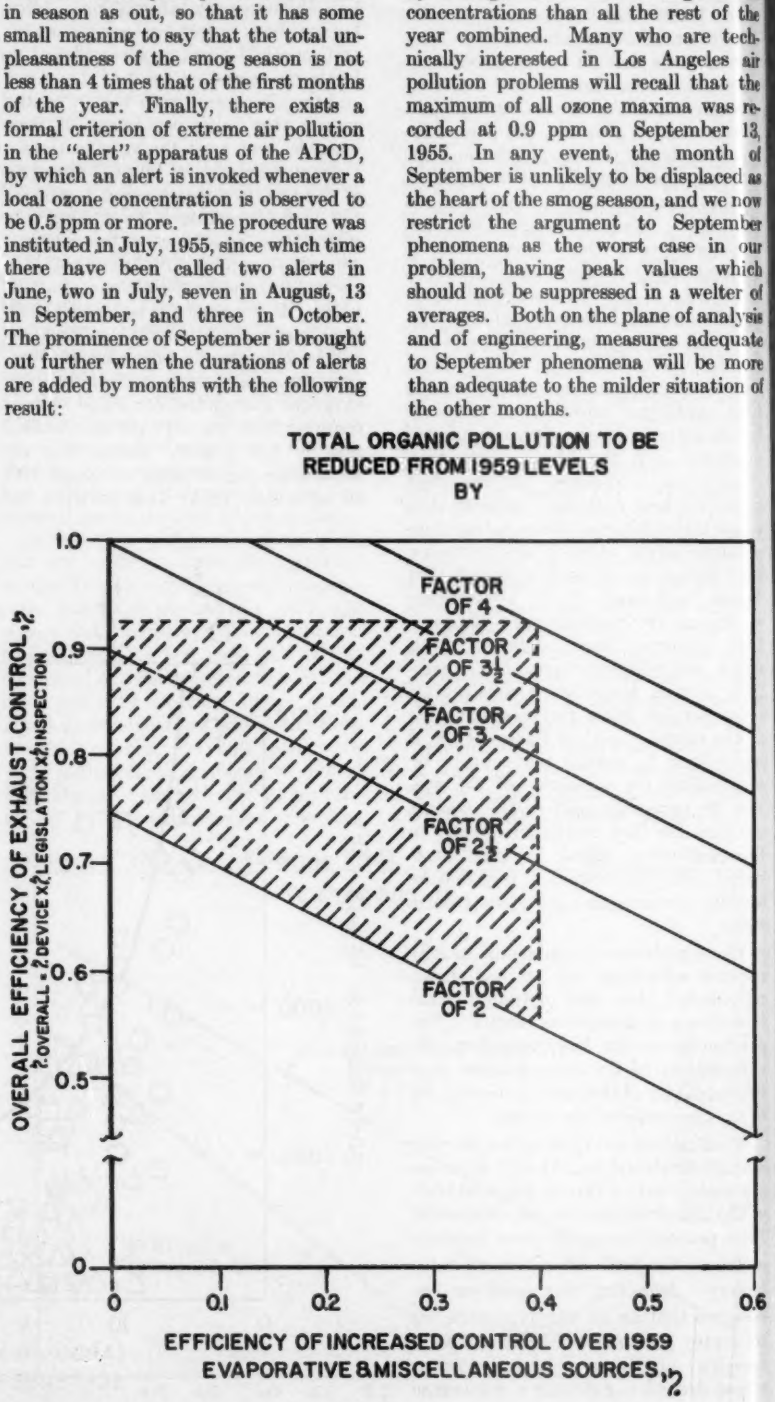


Fig. 3.

Four Septembers

Through the courtesy of Dr. Leslie Chambers of APCD, their day-by-day meteorological and concentration sampling records have been examined for the days in September 1955, 1956, 1957, and 1958. In 1955, 1956, and 1958 meteorological conditions were slightly more than normally adverse for the month and led to totals of seven, six, and two hours of ozone concentration at 0.5 ppm or more, while September 1957, was rather cool and cloudy, and passed without an alert, and with sub-normal eye irritation recorded. It is thought that these four months both typify and comprehend September smog in Los Angeles. Now, in Fig. 2 are entered the daily carbon monoxide maxima measured downtown against the daily heights of the inversion base measured in Santa Monica. If we think of the daily carbon monoxide emission as constant in the absence of a reason why we should not, and idealize the polluted volume to a box with a lid on it we expect a rectangular hyperbola to be in some sense fittable to these points. One such hyperbola, having the formulation

$$[CO] \times h = 22{,}000 \text{ ppm-ft} \quad (1)$$

is proposed in the spirit that it serves as an envelope on most of the points. The distribution of points under and to the left of this hyperbola can be greatly thickened if carbon monoxide maxima from other sampling stations in the basin are added to the plots; a stray point outside the envelope is highly exceptional. If now we estimate (with APCD) a day's carbon monoxide production of 5600 tons and distribute this quantity uniformly under such a lid as is implied by the above written expression (1) the polluted area of the ideal box comes to 240 square miles, which is an acceptable value for the portion of the Los Angeles Basin into which pollution may have been transported at any time.

During the four Septembers we have examined there have been thirteen alerts called, which experience leads us to expect perhaps three or four intolerable days per September. We now bring out from each September the four days of greatest carbon monoxide concentration and form the following array of data for 16 richly polluted days.

It is a measure of the culpableness of these 16 days, selected for their distinction in monoxide, that they coincide with nine alerts out of 13 called, and that an analogous array, selected on the strength of *ozone* concentrations, would coincide in 11 of the 16 entries.

We now take the step of forming a second array of four days from each September, selecting those days distinguished by the weakness of their ozone maxima.

Table I

		Carbon Monoxide Maximum, ppm	Ozone Maximum, ppm	Alert Day?
1955				
Sept.	6	24	0.36	Yes
	12	25	0.40	
	13	25	0.85	Yes
	14	23	0.64	Yes
1956				
Sept.	7	22	0.20	
	26	31	0.55	Yes
	27	32	0.45	Yes
	28	32	0.55	Yes
1957				
Sept.	6	34	0.25	
	12	24	0.18	
	23	27	0.25	
	24	43	0.27	
1958				
Sept.	17	37	0.25	
	18	29	0.53	Yes
	19	36	0.37	Yes
	23	31	0.25	Yes

If the first set of 16 days represented September at its worst, the second set consists of days on which natural conditions like winds, cloudiness, or elevation of the lid inhibited the photochemical reaction leading through ozone to smog. Notice that the character of September, 1955 as rather smoggy and of September, 1957 as rather mild, is preserved in the ozone columns of both arrays.

We now compare the two arrays and ask the following question: what stringency of artificial restraint on the source described by the data of the first array would be expected to yield the data of the second? What must be done to the worst September days to make them like the best September days in recent Los Angeles experience? Comparing first the ozone maxima, we observe that for 1955 we must reduce them by a factor of about five, for 1956 by about five, for 1957 by about six, and for 1958 by

Table II

		Carbon Monoxide Maximum, ppm	Ozone Maximum, ppm
1955			
Sept.	1	19	0.15
	4	14	0.15
	5	7	0.10
	23	6	0.07
1956			
Sept.	1	12	0.10
	2	11	0.10
	5	13	0.10
	11	9	0.05
1957			
Sept.	2	11	0.02
	3	15	0.02
	14	7	0.05
	20	10	0.05
1958			
Sept.	3	11	0.05
	7	13	0.05
	13	10	0.05
	22	12	0.05

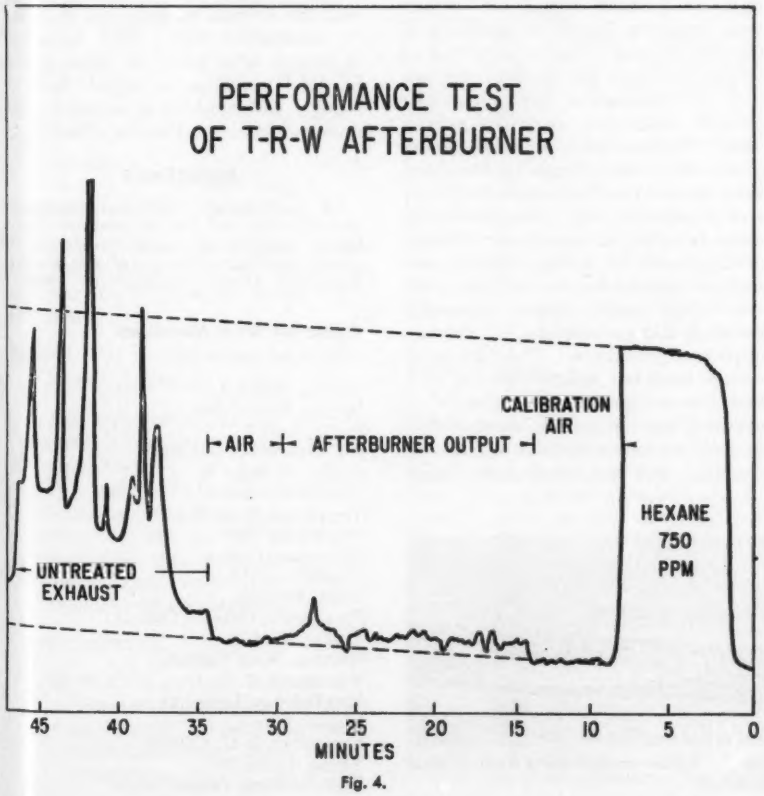


Fig. 4.

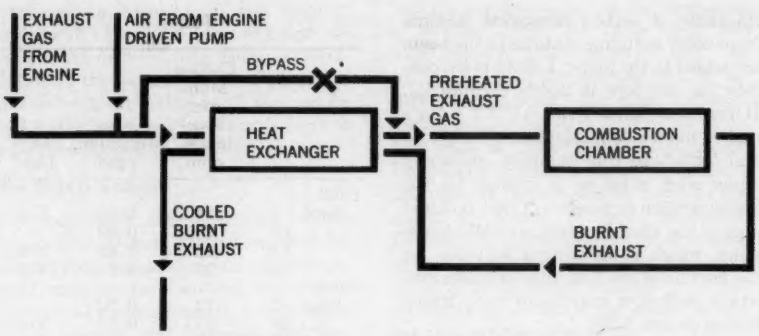


Fig. 5. Schematic diagram of regenerative afterburner system.

about seven. For the associated carbon monoxide maxima the reductions are smaller: for 1955 we must reduce them by a factor of about two, for 1956 by about $2^1/_2$, for 1957 by about $2^1/_2$, for 1958 by about three.

We have been interested in carbon monoxide values as an index to the smog forming organic pollutants. From an envelope drawn over a set of September monoxide maxima we have deduced an ideal box, populated by pollutants whose concentration varies as the lid of the box moves up and down from day to day. Selection from the September experience discloses a factor of two or three in pollution level between the worst days and the best. At this point, the formulation of a policy of control becomes a matter of art and judgment, but we suggest that it is reasonable to stay within the meteorological and natural constraints on the month of September, and try to reduce the worst September experience to the level of the best. It follows that a pollutant which contributes to the smog-forming reaction must be reduced in concentration within the box by a factor of two or three.

It must be recognized that in this analysis we have derived our estimates of the necessary reduction from the meteorological modulation of the concentration of pollution, using carbon monoxide as a tracer for the concentration of the organic pollutants. In this natural modulation the organic and the oxides of nitrogen concentrations are reduced simultaneously. The prediction of the results of man's reducing the organic pollution from nature's reductions of the concentrations of both pollutants may be somewhat defended on two grounds. First, the suggested reduction of the organic pollution must certainly be carried out. Second, the eye irritant and visibility reducing material is believed to be constructed of the debris from the photochemical degradation of hydrocarbons and other organics, and it is reasonable to expect that reduction of the organic pollutants will reduce these effects proportionally. However, the influence of varying oxides of nitrogen concentration needs further study, and if the results of such studies indicate that equivalent reduction in oxides of nitrogen is needed then yet another means of control must be found and added.

In order to illustrate the possibilities for over-all reduction of the present pollution Fig. 3 has been constructed. Here are plotted contours of several total reduction factors as functions of the efficiencies of exhaust control and of increased control on all other sources, with the assumption that automobile exhaust contributes $^2/_3$ of the present total. On this figure we concern ourselves with a shaded region in the upper left, bounded by a horizontal, a vertical, and a slanting line. The horizontal upper boundary at an over-all efficiency of 0.92 represents the best exhaust control it is reasonable to expect from a device of high quality, almost universally installed, and governed by the strictest inspection procedures. The right hand vertical boundary indicates our estimate that the strength of other sources of pollution may be reduced another 40% by such measures as controls on evaporation, but that larger reductions might prove to be prohibitively costly. Finally, the slanting boundary coincides with the contour for a reduction by a factor of two from the present level of pollution, which is the smallest reduction we dare to pursue, remembering the large costs of automotive regulation, inspection, controls, and devices.

The intersections of these reduction factor contours with horizontal lines at over-all efficiencies of 0.9 and 0.8 show that a 90% reduction of exhaust pollution need be accompanied by only a small improvement in the control on other sources if the goal of a factor of three reduction in the total pollution is to be met. If it should prove feasible to reduce other pollution by a factor of two, the same goal can be met by an effectiveness of exhaust control of 75%, which effectiveness would require 90% devices in operation on 83% of the cars. Were an 80% device installed on 90% of the cars, the goal of a factor of three reduction in the total could only be achieved at a 60% effectiveness of increased control over other sources, though a factor of two could be achieved with minor improvement in the control of other sources. It is clear that 80% is the minimum acceptable efficiency for a device to control present pollution levels. If the population of Los Angeles is estimated to double in the reasonably near future, the efficiencies required can be estimated from the contour for a factor of four reduction from present totals, where we see that a 90% device with an over-all effectiveness of 80%, in combination with a 60% reduction of today's other pollution, would result in total pollution of about half of today's, and hopefully in a considerable improvement over today's situation.

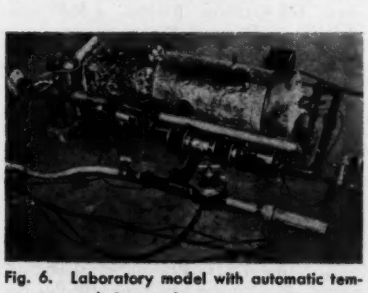


Fig. 6. Laboratory model with automatic temperature and air control.

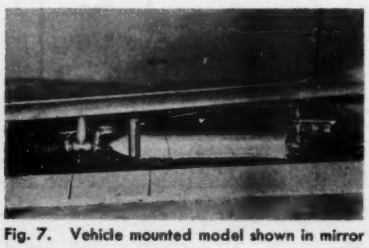


Fig. 7. Vehicle mounted model shown in mirror under car.

REFERENCE

[1] S. L. Ridgway, "Homogeneous Reaction Kinetics and the Afterburner Problem," preprint of paper presented to annual meeting of Society of Automotive Engineers, Detroit, January 16, 1959.

Welcome New Members

(*Continued from p. 291*)

Sinning, Frank A.
Rockey River, Ohio
Smith, Ross A.
San Francisco, California
Stalker, William W.
Cincinnati, Ohio
Templeton, Hugh E.
Cincinnati, Ohio
Thompson, C. Ray
Riverside, Calif.
Todd, Malcolm
Port Credit, Ontario, Canada
Tucker, Fred E.
Weirton, West Virginia
Van Dusen, G. T., Jr.
Port Sulphur, Louisiana
Walter, John L.
Vancouver, B. C., Canada
Young, James W.
Hollidaysburg, Pennsylvania

1960 CLEANER AIR WEEK TO BE HELD IN OCTOBER; AIR POLLUTION CITED AS 'EVERYBODY'S BUSINESS'

APCA's 1960 Cleaner Air Week is being celebrated the week of October 23 to 29. It is a significant step toward the chief aim of our organization—air pollution control.

Cleaner Air Week is based on the one general area of agreement about pollution control. That is, that it's everybody's business. Each of us, as a polluter and sufferer, has a personal stake in pollution control, but is helpless by himself. We have to tackle the job on a team basis.

One of the Association's principal objectives in establishing Cleaner Air Week 12 years ago was to promote the public understanding necessary to enlist all of us in a community-wide approach to pollution control.

CAW is directed by APCA's National Cleaner Air Week Committee from the Cincinnati offices of Chairman Charles Howison. Local Cleaner Air Week Committees in scores of cities across the nation are the operating units of the campaign.

Your Local CAW Committee

Objectives

1 Understanding of your community's air pollution control problems.
2 Awareness of pollution control progress.
3 Acceptance of the community-wide approach to air pollution control.

Personnel

Your committee should represent such principal segments of air pollution control interest as:

Trade Civic and Professional Associations	Transportation
Government	Labor Organizations
Radio and Television	Retail Business
Newspapers	Control Equipment Mfgs.
Industry	Education

The committee membership should represent public relations capability covering the entire range of the CAW program.

Budget

National promotion expense

1 The area committee will have no fixed cost to bear for any national promotions.
2 For whatever posters individual industrial firms may purchase and whatever materials the local CAW committee may purchase through the national committee, charges are incurred voluntarily.

Local expenses

1 Much of the cost goes underground.
   a Personnel committments make up the principal contributions of organizations represented on the committee.
   b Use of release production facilities is a good example of hidden cost which, previous experience indicates, committee members are able to assume through the use of their own facilities.
2 Minor expenses not presently anticipated may be defrayed as they are incurred and shared later as determined by the committee.

No two CAW Committees will set up alike and the following organization is offered only as a suggestion.

Organization

The work of this hypothetical CAW committee is divided six ways and these divisions are partitioned into sectional assignments of reasonable size so that each individual can handle his job without great sacrifice.

Defining committee assignments specifically in this way fixes responsibility and avoids the "who should do what" question.

City Desk—CAW-Committee Chairman, co-ordinates division activities. Relays National CAW promotion material to divisions. Posts National CAW Committee on local Committee's progress; News Division—Public Relations men; Radio and Television Division; Speakers Division; Special Events Division; Advertising Division.

Special Days

Throughout Cleaner Air week, special days have been designated to emphasize specific objectives of the campaign. It is hoped that those organizations and groups who are specifically interested will work with the local committee.

Sunday—Community Sunday, on this opening day stress the importance of the community-wide approach to air pollution control.

Monday—Housekeeping Day, collect rubbish, dirt, and waste materials for pick-up. Do not burn. Junior Chamber of Commerce may undertake promotion of this effort.

Tuesday—Home Heating Day, clean furnace, flues. Check maintenance needs. Clean chimney. Co-ordinate with furnace cleaning firm.

Wednesday—Automobile Day, does your exhaust pipe smoke? Co-ordinate inspection drive.

Thursday—Industry Day, arrange industry tours for air pollution control progress of your community plants.

Friday—Air Pollution Control Official Day, publicize the work of your air pollution control officials; pay tribute to their important public service.

Saturday—Examination Day, grade your community-wide efforts in all phases of air pollution control.

Berton Karol Talks At AIHA Annual Meet

"Automotive Exhaust Fume Purification by Catalytic Oxidation" was the subject of talks given by Berton Karol, Manager of the Automotive Division of Oxy-Catalyst, Inc., Devon Pa., at the 21st Annual Meeting of the American Industrial Hygiene Association at the New War Memorial Auditorium, Rochester, N. Y., on April 27, 1960.

Mr. Karol outlined the growth of indoor and outdoor air pollution caused by the discharge of automotive exhaust fumes into the atmosphere or in buildings. He pointed out the health and safety hazards created by exhaust fumes, not only from deadly carbon monoxide but also from cancer suspect hydrocarbons. Mr. Karol talked about the purifier that his firm has been marketing for inplant vehicles over the 10 years, plus the work Oxy-Catalyst has been doing in developing an anti-smog device for automobiles and buses in cooperation with a major automobile manufacturer.

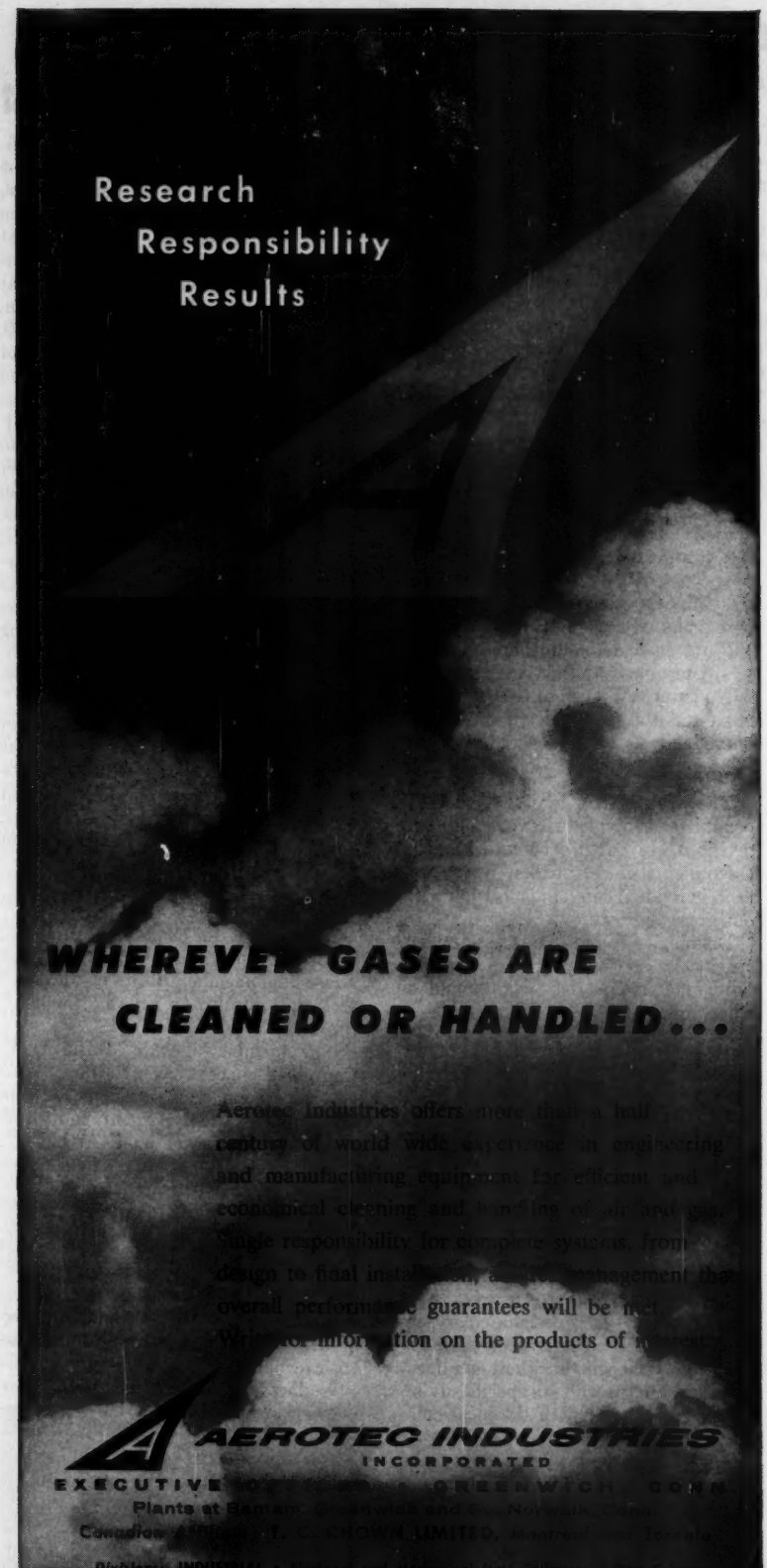
Mr. Karol, a graduate engineer of Drexel Institute in Philadelphia, has been closely associated with this subject for over 10 years and is considered a pioneer and authority in this area. Copies of his paper are available from Oxy-Catalyst, Inc., Devon, Pa.

BOARD EXPANDS

As part of an expansion program, American Incinerator Corporation has added four members to its board of directors, according to Ellis E. Smauder, president.

New members include Marlin J. W. Campbell, corporation attorney; Walter F. Finan, vice-president of the City Bank; A. M. Sargent, industrial consulting engineer; and Arthur C. Scheifle, of MacManus, John, and Adams, Inc., advertising agency.

Continuing on the board are Ellis E. Smauder, president; Alden Smauder, secretary-treasurer; and R. D. Bond, CPA.



TA-2 COMMITTEE REPORT

(*Continued from page 298*)

wasted food products has been the subject of much discussion during the past five years. Engineering studies by Michigan State College, the University of California at Berkeley, and others now provide sound engineering bases for the composting of organic waste materials. Open field composting through storage in windrows, with the windrows turned about twice weekly and decomposition satisfactorily completed in approximately two to three weeks' time, can be accomplished without the objectionable odors much beyond the area of operation. It is recommended that such open field composting be done only in areas with similar isolation as is normally afforded hog ranches, dairies, and other such operations involving manures. Other composting processes which involve closed mechanical units are usually quite free from odor nuisance and are no more sources of air pollution than the majority of industrial processes. Because of the raw material handled, to wit, garbage, waste paper, cardboard, grass and leaves, etc., the operation should preferably be conducted in a manufacturing or industrial zone to prevent complaints from the odors that are bound to be associated with the handling of such materials. The finished compost can be satisfactorily stored in open piles without producing nuisance, except that a musty odor will be released from the piles following rain. In general, composting is relatively free from odor nuisances, provided reasonable care is taken during the operation to protect against improper procedures which lead to the anaerobic decay of organic material.

Committee Members

F. R. Bowerman, Chairman, R. C. Corey, R. Eliassen, L. P. Flood, G. P. Larson, A. H. Rose, Jr., E. E. Smauder, H. H. Uhlrich, V. Westergaard.

REFERENCE

1. APCA Abstracts, No. 323.

REPRINTS
of
Journal Articles
and
Annual Meeting Papers
Available Through APCA HEADQUARTERS.

STANDARD ZONING

(Continued from page 284)

2. A. J. Bone and Martin Wohl, "Industrial Development Survey on Massachusetts Route 128," *Highway Research Board, Bulletin 189.* Washington: Highway Research Board (1958).
Dorothy A. Muncy, "Planning Highways for Industrial Development," *Proceedings* 44th Annual Road School, Purdue University. Lafayette: Purdue University (1958).
3. Dorothy A. Muncy, *Industrial Land Development,* Planning Report No. 2, Baltimore Regional Planning Council. Baltimore: Maryland State Planning Commission (1959).
4. National Industrial Zoning Committee "Principles of Industrial Zoning.' Columbus, Ohio: National Industrial Zoning Committee (1951).
Dennis O'Harrow, "Performance Standards in Industrial Zoning." Columbus, Ohio: National Industrial Zoning Committee (1955).
Dennis O'Harrow, "Steps to Secure Sound Zoning." Columbus, Ohio: National Industrial Zoning Committee (1957).

T1-8 COMMITTEE REPORT

(Continued from page 296)

operations but discharge the fume directly into the atmosphere.

Arsenic is sometimes introduced into lead as an alloying component in the form of arsenic metal or as arsenic trioxide. In operations of this nature the steel melting kettle is hooded in such a manner as to cover the entire exposed surface of the molten metal, during the arsenic additions. The fumes generated are removed by a fan from the hood into a cooling unit to condense the metallic vapors and then filtered in a baghouse with an efficiency of about 99% before being discharged into the atmosphere in amounts well below the ordinance requirements.

Committee Members

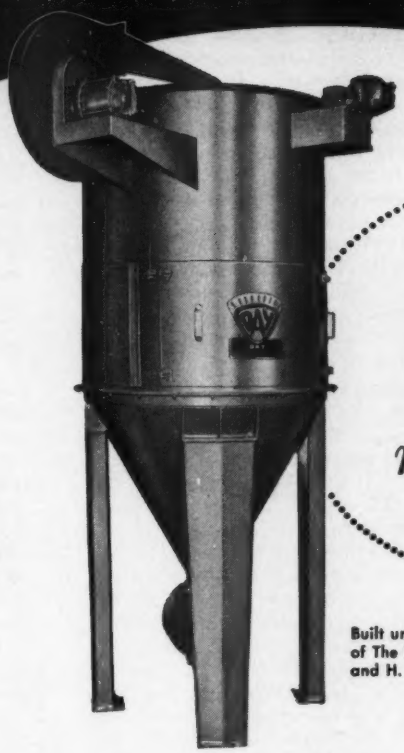
V. C. Doerschuk, Chairman, D. J. Blythe, M. E. Brooks, W. R. Chalker, H. E. Furgeson, J. Jewell, A. L. Koven, R. E. Kunkle, R. S. McNair, L. V. Olson, F. B. Shay, A. F. Snowball, H. W. Zeh.

CLASSIFIED

PROFESSIONAL ENGINEER—To assist in the development and administration of an expanded air pollution control program on a state-wide basis. Requirements: Academic degree in engineering, registered professional engineer, considerable experience in industrial hygiene and/or air pollution. Salary range: $7920 to $9420 annually. Employee Benefits: Civil Service appointment, excellent retirement system, sick leave, paid vacation and travel expenses. Address reply to: H. G. Bourne, Jr., Ohio Department of Health, Room 306, Ohio Departments Building, Columbus 15, Ohio.

New DAY "RJ" Dust Filter

CONTROLS DUST SAVES DOLLARS



only 3 moving parts

Built under patents of The DAY Company and H. J. Hersey, Jr.

Because of its new, simplified design the DAY "RJ" dust filter will save you many dollars on initial investment, installation, operation and maintenance. Some of the important new construction features of this dust filter are: a new, quick-opening reverse-air, counter-flow valve for maintaining filter media porosity; a new, reverse-air pressure blower arrangement, and new, air tight, yet quickly opened inspection doors.

This patented DAY dust filter has only 3 moving parts but controls dust effectively, efficiently (99.99+%) and economically. It represents the latest refinement in a long-tested, plant-proven dust filter. Using felted filter sleeves to capture dust, the "RJ" is now available in 5 sizes for handling from 300 to 6400 CFM of air (for larger capacities, multiple groupings are furnished).

For more detailed information write toDAY for free Bulletin G-30. It's filled with facts, specifications and dimensions.

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EQUIPMENT . . . SYSTEMS . . . INSTALLATION

Nominate Your Award Candidate

The Awards Committee, Jack H. Smith, chairman, is requesting nominations for the Frank A. Chambers and Richard Beatty Mellon Awards, and Honorary Memberships. Your nominations should be sent to: J. H. Smith, Dir., Air Control and Research Dept., Kaiser Steel Corp., P. O. Box 217, Fontana, Calif.

Frank A. Chambers Award

This award was established by resolution of the Board of Directors on February 12, 1954, to be awarded to an individual "for outstanding achievement in the control of air pollution." It may be awarded to members or nonmembers of APCA.

Eligibility for this award requires a specific act on the part of the recipient which is considered to be a major contribution to the science of air pollution control. It is not awarded for general excellence of work or prominence in the field.

Frank A. Chalmers (1885–1951) was a founder of the Smoke Prevention Association of America, forerunner of APCA, and almost single-handedly established the foundation of our present Association. His ideas have been put into operation in many cities in the United States.

Richard Beatty Mellon Award

This award is given to the individual "whose contributions of a civic, administrative, technical or other nature have aided substantially the cause of air pollution control." It may be awarded to members or nonmembers of APCA.

Eligibility for the award requires the sincere and constant effort of an individual over a period of time to develop or increase interest in or acceptance of the cause of air pollution control. It is awarded to that individual who, through unselfish interest and in a manner best suited to his own resources has furthered the cause of air pollution control.

Richard Beatty Mellon (1858–1933), in the desire to benefit mankind, with his brother Andrew William Mellon, established the Mellon Institute of Industrial Research in 1913. Mr. Mellon showed great interest in the abatement of urban smoke and air pollution. He was the leader in inceptng and sustaining the first modern investigations looking to ways and means for controlling the pollution of our atmosphere.

Honorary Memberships

Honorary memberships are conferred on persons "of widely recognized eminence in some part of the field of air pollution control which the Association aims to cover," or who have "rendered especially meritorious service to the Association." This may be conferred on members or nonmembers of APCA.

How to Nominate Candidates

1 Your nomination, in the form of a letter, shall contain:
   - *a* The full name, address and business affiliation, including title, of the nominee;
   - *b* Designation of the Honor or Award for which he is being nominated:
   - *c* A concise and explicit statement of the attainment or achievement which, in your opinion, entitles the nominee to the award. (This may form the basis for a citation and care should be given to its preparation.);
   - *d* A brief biography of the nominee;
   - *e* Any additional information which you may feel may assist the Awards Committee in arriving at a decision.

2 Nominating letters shall contain:
   - *a* For Honorary Membership, a minimum of twenty-five (25) signatures of members of the Association;
   - *b* For the Frank A. Chambers and Richard Beatty Mellon Awards, the names of at least three (3) persons who have first-hand knowledge of subject matter requested in 1 (c).

3 Letters of nomination will be accepted from nonmembers as well as members of APCA. Be sure to state whether the nominee is sponsored by you individually, or by an organization you represent.

4 Nominations shall be received by the Awards Committee not later than Jan. 1, to be considered at the next annual meeting.

Air Pollution Control Association Membership Blank

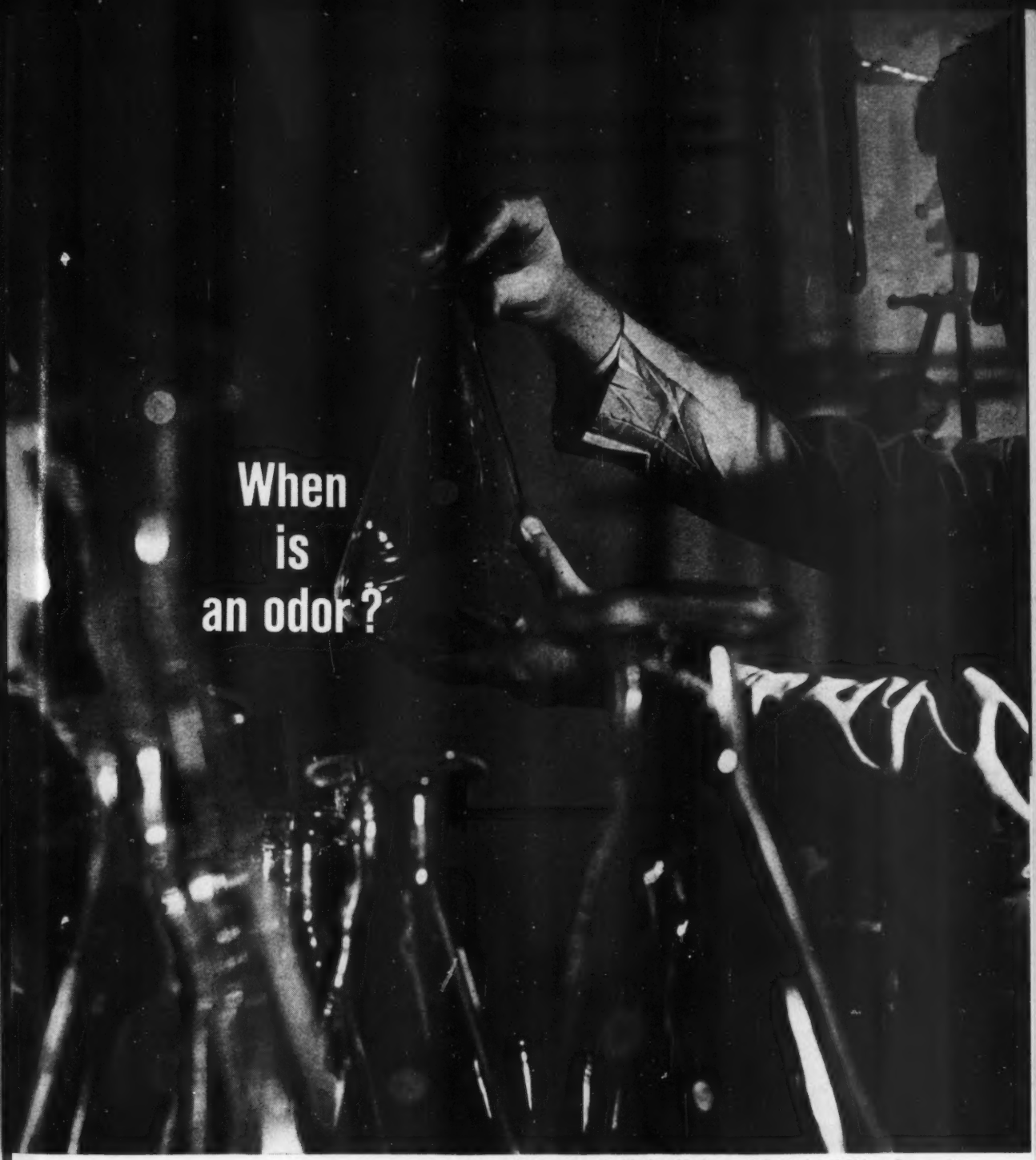
1. **Name (or company name)**.....
2. **Mailing address**.....
3. **Individual members: Company, organization, or agency with whom you are affiliated**.....
   Company or Sustaining members: Industry affiliation or type of business (steel, petroleum, equipment, etc.)....
   .....
4. **Class of Membership (please check)**

	Dues
Individual ☐	**$ 10.00**
Company ☐	**50.00**
Sustaining ☐	**250.00 Minimum**

5. **Check enclosed herewith** ☐
   Send bill for dues ☐
6. **Company or sustaining member's delegated voting representative is:**
   Name.....
   Title.....
   Address.....

7. **Signed**.....
   Title.....
   Date.....

Here is an opportunity to help your Association get its membership campaign off the ground. Use this application blank for new individual, company or sustaining members. If each APCA member brings in just one new member, we'll be well over the 4000 mark.



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Write for a detailed bulletin on odors, their technology and control. Airkem, Inc., Industrial Division, Dept. AP-860, 241 East 44th St., New York 17, N. Y.

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